

8.2 Structure of DNA

VOCABULARY

nucleotide
double helix
base pairing rules

KEY CONCEPT DNA structure is the same in all organisms.

MAIN IDEAS

- ▶ DNA is composed of four types of nucleotides.
- ▶ Watson and Crick developed an accurate model of DNA's three-dimensional structure.
- ▶ Nucleotides always pair in the same way.

Connect to Your World

The experiments of Hershey and Chase confirmed that DNA carries the genetic information, but they left other big questions unanswered: What exactly is this genetic information? How does DNA store this information? Scientists in the early 1950s still had a limited knowledge of the structure of DNA, but that was about to change dramatically.

▶ MAIN IDEA

DNA is composed of four types of nucleotides.

Since the 1920s, scientists have known that the DNA molecule is a very long polymer, or chain of repeating units. The small units, or monomers, that make up DNA are called **nucleotides** (NOO-klee-uh-tydz). Each nucleotide has three parts.

- A phosphate group (one phosphorus with four oxygens)
- A ring-shaped sugar called deoxyribose
- A nitrogen-containing base (a single or double ring built around nitrogen and carbon atoms)

One molecule of human DNA contains billions of nucleotides, but there are only four types of nucleotides in DNA. These nucleotides differ only in their nitrogen-containing bases.

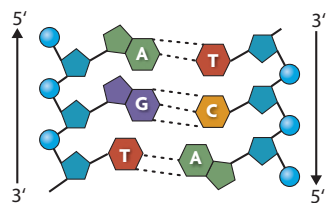
The four bases in DNA are shown in **FIGURE 2.1**. Notice that the bases cytosine (C) and thymine (T) have a single-ring structure. Adenine (A) and guanine (G) have a larger, double-ring structure. The letter abbreviations refer both to the bases and to the nucleotides that contain the bases.

For a long time, scientists hypothesized that DNA was made up of equal amounts of the four nucleotides, and so the DNA in all organisms was exactly the same. That hypothesis was a key reason that it was so hard to convince scientists that DNA was the genetic material. They reasoned that identical molecules could not carry different instructions across all organisms.

CONNECT TO

BIOCHEMISTRY

The nucleotides in a strand of DNA all line up in the same direction. As a result, DNA has chemical polarity, which means that the two ends of the DNA strand are different. The 5' carbon is located at one end of the DNA strand, and the 3' carbon is located at the other end. When the two strands of DNA pair together, the 5' end of one strand aligns with the 3' end of the other strand.



VISUAL VOCAB

The small units, or monomers, that make up a strand of DNA are called **nucleotides**. Nucleotides have three parts.

phosphate group

nitrogen-containing base

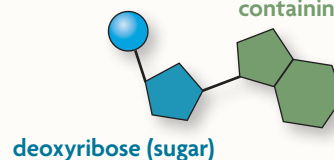


FIGURE 2.1 The Four Nitrogen-Containing Bases of DNA

| PYRIMIDINES = SINGLE RING | | | PURINES = DOUBLE RING | | |
|---------------------------|--------------------|-------|-----------------------|--------------------|-------|
| Name of Base | Structural Formula | Model | Name of Base | Structural Formula | Model |
| thymine | | | adenine | | |
| cytosine | | | guanine | | |

Compare Which base is most similar in structure to thymine?

By 1950 Erwin Chargaff changed the thinking about DNA by analyzing the DNA of several different organisms. Chargaff found that the same four bases are found in the DNA of all organisms, but the proportion of the four bases differs somewhat from organism to organism. In the DNA of each organism, the amount of adenine approximately equals the amount of thymine. Similarly, the amount of cytosine roughly equals the amount of guanine. These A = T and C = G relationships became known as Chargaff's rules.

Summarize How do the four DNA nucleotides differ in structure?

MAIN IDEA

Watson and Crick developed an accurate model of DNA's three-dimensional structure.

The breakthrough in understanding the structure of DNA came in the early 1950s through the teamwork of American geneticist James Watson and British physicist Francis Crick. Watson and Crick were supposed to be studying the structure of proteins. Both men, however, were more fascinated by the challenge of figuring out DNA's structure. Their interest was sparked not only by the findings of Hershey, Chase, and Chargaff but also by the work of the biochemist Linus Pauling. Pauling had found that the structure of some proteins was a helix, or spiral. Watson and Crick hypothesized that DNA might also be a helix.

X-Ray Evidence

At the same time, Rosalind Franklin, shown in **FIGURE 2.2**, and Maurice Wilkins were studying DNA using a technique called x-ray crystallography. When DNA is bombarded with x-rays, the atoms in DNA diffract the x-rays in a pattern that can be captured on film. Franklin's x-ray photographs of DNA showed an X surrounded by a circle. Franklin's data gave Watson and Crick the clues they needed. The patterns and angle of the X suggested that DNA is a helix consisting of two strands that are a regular, consistent width apart.

READING TOOLBOX

VOCABULARY

An amine is a molecule that contains nitrogen. Notice that the four DNA bases end in *-ine* and all contain nitrogen.



Rosalind Franklin

FIGURE 2.2 Rosalind Franklin (above) produced x-ray photographs of DNA that indicated it was a helix. Her coworker, Maurice Wilkins, showed the data without Franklin's consent to Watson and Crick, which helped them discover DNA's structure.

FIGURE 2.3 James Watson (left) and Francis Crick (right) used a model to figure out DNA's structure. Their model was influenced by data from other researchers, including an x-ray image (far right) taken by Rosalind Franklin. When x-rays bounce through a sample of DNA, they form this characteristic x-shaped pattern.



James Watson and Francis Crick



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PREMIUM CONTENT
DNA Structure

The Double Helix

Back in their own laboratory, Watson and Crick made models of metal and wood to figure out the structure of DNA. Their models placed the sugar-phosphate backbones on the outside and the bases on the inside. At first, Watson reasoned that A might pair with A, T with T, and so on. But the bases A and G are about twice as wide as C and T, so this produced a helix that varied in width. Finally, Watson and Crick found that if they paired double-ringed nucleotides with single-ringed nucleotides, the bases fit like a puzzle.

In April 1953 Watson and Crick published their DNA model in a paper in the journal *Nature*. **FIGURE 2.3** shows their **double helix** (DUB-uhl HEE-likes) model, in which two strands of DNA wind around each other like a twisted ladder. The strands are complementary—they fit together and are the opposite of each other. That is, if one strand is ACACAC, the other strand is TGTGTG. The pairing of bases in their model finally explained Chargaff's rules.

Apply How did the Watson and Crick model explain Chargaff's rules?

▶ MAIN IDEA

Nucleotides always pair in the same way.

The DNA nucleotides of a single strand are joined together by covalent bonds that connect the sugar of one nucleotide to the phosphate of the next nucleotide. The alternating sugars and phosphates form the sides of a double helix, sort of like a twisted ladder. The DNA double helix is held together by hydrogen bonds between the bases in the middle. Individually, each hydrogen bond is weak, but together, they maintain DNA structure.

As shown in **FIGURE 2.4**, the bases of the two DNA strands always pair up in the same way. This is summarized in the **base pairing rules**: thymine (T) always pairs with adenine (A), and cytosine (C) always pairs with guanine (G). These pairings occur because of the sizes of the bases and the ability of the

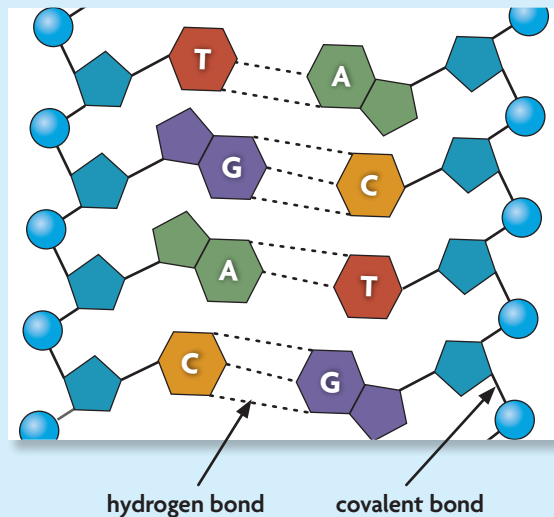
CONNECT TO

CHEMICAL BONDS

Recall from **Chemistry of Life** that a covalent bond is a strong bond in which two atoms share one or more pairs of electrons. Hydrogen bonds are much weaker than covalent bonds and can easily be broken.

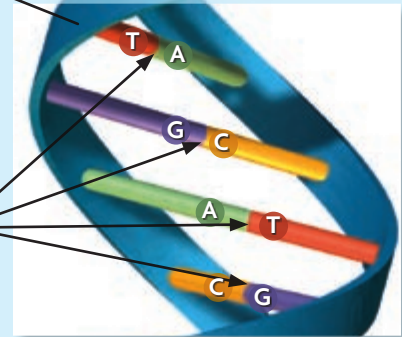
FIGURE 2.4 Base Pairing Rules

The **base pairing rules** describe how **nucleotides** form pairs in DNA. T always pairs with A, and G always pairs with C.



This ribbonlike part represents the **phosphate groups** and **deoxyribose sugar** molecules that make up DNA's "backbone."

The nitrogen-containing bases form hydrogen bonds in the middle to form the rungs of the DNA ladder.



Synthesize Which base pairs do you think are held more tightly together? Why?

bases to form hydrogen bonds with each other. Due to the arrangement of their molecules, A can form unique hydrogen bonds with T, and C with G. Notice that A and T form two hydrogen bonds, whereas C and G form three.

You can remember the rules of base pairing by noticing that the letters C and G have a similar shape. Once you know that C and G pair together, you know that A and T pair together by default. If a sequence of bases on one strand of DNA is CTGCTA, you know the other DNA strand will be GACGAT.

Apply What sequence of bases would pair with the sequence TGACTA?

8.2 Formative Assessment

REVIEWING MAIN IDEAS

1. How many types of **nucleotides** are in DNA, and how do they differ?
2. How are the **base pairing rules** related to Chargaff's research on DNA?
3. Explain how the **double helix** model of DNA built on the research of Rosalind Franklin.

CRITICAL THINKING

4. **Infer** Which part of a DNA molecule carries the genetic instructions that are unique for each individual: the sugar-phosphate backbone or the nitrogen-containing bases? Explain.
5. **Predict** In a sample of yeast DNA, 31.5% of the bases are adenine (A). Predict the approximate percentages of C, G, and T. Explain.



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PREMIUM CONTENT

CONNECT TO

EVOLUTION

6. The DNA of all organisms contains the same four bases (adenine, thymine, cytosine, and guanine). What might this similarity indicate about the origins of life on Earth?