The Structure of DNA

Key Questions

What are the chemical components of DNA?

What clues helped scientists solve the structure of DNA?

What does the double-helix model tell us about DNA?

Vocabulary

base pairing

Taking Notes

Outline As you read, find the key ideas for the text under each green heading. Write down a few key words from each main idea. Then, use these key words to summarize the information about DNA.

THINK ABOUT IT It's one thing to say that the molecule called DNA carries genetic information, but it would be quite another thing to explain how it could do this. DNA must not only specify how to assemble proteins, but how genes can be replicated and inherited. DNA has to be a very special molecule, and it's got to have a very special structure. As we will see, understanding the structure of DNA has been the key to understanding how genes work.

The Components of DNA

What are the chemical components of DNA?

Deoxyribonucleic acid, or DNA, is a unique molecule indeed. **DNA is a nucleic acid made up of nucleotides joined into long strands or chains by covalent bonds.** Let's examine each of these components more closely.

Nucleic Acids and Nucleotides As you may recall, nucleic acids are long, slightly acidic molecules originally identified in cell nuclei. Like many other macromolecules, nucleic acids are made up of smaller subunits, linked together to form long chains. Nucleotides are the building blocks of nucleic acids. **Figure 12–5** shows the nucleotides in DNA. These nucleotides are made up of three basic components: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous base.

Nitrogenous Bases and Covalent Bonds Nitrogenous bases, simply put, are bases that contain nitrogen. DNA has four kinds of nitrogenous bases: adenine (AD uh neen), guanine (GWAH neen), cytosine (SY tuh zeen), and thymine (THY meen). Biologists often refer to the nucleotides in DNA by the first letters of their base names: A, G, C, and T. The nucleotides in a strand of DNA are joined by covalent bonds formed between the sugar of one nucleotide and the phosphate group of the next. The nitrogenous bases stick out sideways from the nucleotide chain. The nucleotides can be joined together in any order, meaning that any sequence of bases is possible. These bases, by the way, have a chemical structure that makes them especially good at absorbing ultraviolet (UV) light. In fact, we can determine the amount of DNA in a solution by measuring the amount of light it absorbs at a wavelength of 260 nanometers (nm), which is in the UV region of the electromagnetic spectrum.

MYSTERY CLUE

The energy from UV light can excite electrons in the absorbing substance to the point where the electrons cause chemical changes. What chemical changes might occur in the nitrogenous bases of DNA?

If you don't see much in **Figure 12–5** that could explain the remarkable properties of DNA, don't be surprised. In the 1940s and early 1950s, the leading biologists in the world thought of DNA as little more than a string of nucleotides. They were baffled, too. The four different nucleotides, like the 26 letters of the alphabet, could be strung together in many different sequences, so it was possible they could carry coded genetic information. However, so could many other molecules, at least in principle. Biologists wondered if there were something more to the structure of DNA.

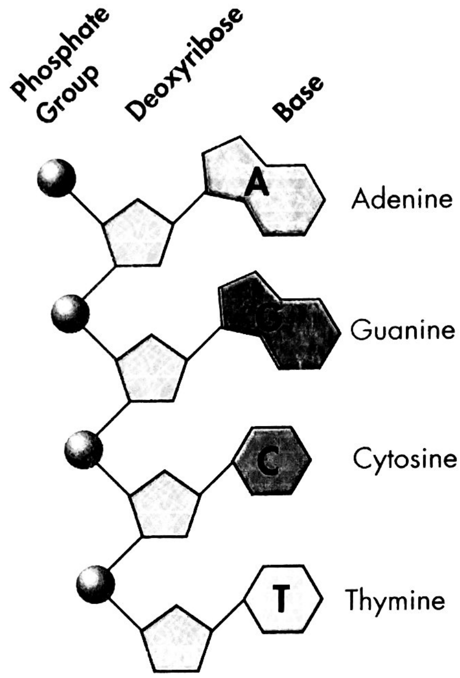


FIGURE 12–5 DNA Nucleotides DNA is made up of nucleotides, each with a deoxyribose molecule, a phosphate group, and a nitrogen-containing base. The four bases are adenine (A), guanine (G), cytosine (C), and thymine (T). **Interpret Visuals** ***How are these four nucleotides joined together to form part of a DNA chain?***

Solving the Structure of DNA

What clues helped scientists solve the structure of DNA?

Knowing that DNA is made from long chains of nucleotides was only the beginning of understanding the structure of this molecule. The next step required an understanding of the way in which those chains are arranged in three dimensions.

Chargaff's Rule One of the puzzling facts about DNA was a curious relationship between its nucleotides. Years earlier, Erwin Chargaff, an Austrian-American biochemist, had discovered that the percentages of adenine [A] and thymine [T] bases are almost equal in any sample of DNA. The same thing is true for the other two nucleotides, guanine [G] and cytosine [C]. The observation that [A] = [T] and [G] = [C] became known as "Chargaff's rule." Despite the fact that DNA samples from organisms as different as bacteria and humans obeyed this rule, neither Chargaff nor anyone else had the faintest idea why.

Analyzing Data

Base Percentages

In 1949, Erwin Chargaff discovered that the relative amounts of A and T, and of G and C, are almost always equal. The table shows a portion of the data that Chargaff collected.

Percentages of Bases in Five Organisms

Source of DNA	A	T	G	C
Streptococcus	29.8	31.6	20.5	18.0
Yeast	31.3	32.9	18.7	17.1
Herring	27.8	27.5	22.2	22.6
Human	30.9	29.4	19.9	19.8
E.coli	24.7	23.6	26.0	25.7

1. Interpret Tables Which organism has the highest percentage of adenine?

2. Calculate If a species has 35 percent adenine in its DNA, what is the percentage of the other three bases? MATH

3. Draw Conclusions What did the fact that A and T, and G and C, occurred in equal amounts suggest about the relationship among these bases?

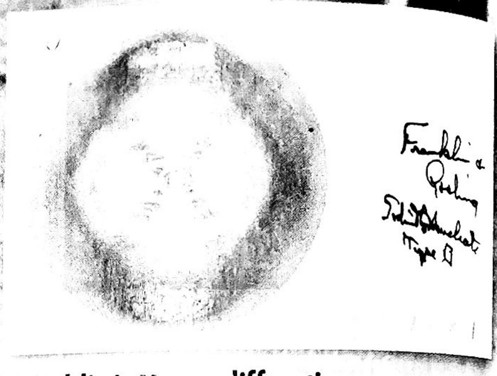
Rosalind Franklin

VISUAL SUMMARY

CLUES TO THE STRUCTURE OF DNA

FIGURE 12–6 Erwin Chargaff, Rosalind Franklin, James Watson, and Francis Crick were among the many scientists who helped solve the puzzle of DNA's molecular structure. Franklin's X-ray diffraction photograph shows the pattern that indicated the structure of DNA is helical.

Erwin Chargaff



Franklin's X-ray diffraction photograph, May 1952

Franklin's X-Rays In the early 1950s, the British scientist Rosalind Franklin began to study DNA. Franklin used a technique called X-ray diffraction to get information about the structure of the DNA molecule. First, she purified a large amount of DNA, then stretched the DNA fibers in a thin glass tube so that most of the strands were parallel. Next, she aimed a powerful X-ray beam at the concentrated DNA samples and recorded the scattering pattern of the X-rays on film. Franklin worked hard to obtain better and better patterns from DNA until the patterns became clear. The result of her work is the X-ray photograph shown in **Figure 12–6,** taken in the summer of 1952.

By itself, Franklin's X-ray pattern does not reveal the structure of DNA, but it does carry some very important clues. The X-shaped pattern shows that the strands in DNA are twisted around each other like the coils of a spring, a shape known as a **helix.** The angle of the X suggests that there are two strands in the structure. Other clues suggest that the nitrogenous bases are near the center of the DNA molecule.

BUILD Vocabulary

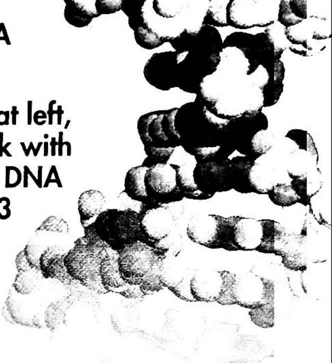
ACADEMIC WORDS In biochemistry, the noun **helix** refers to an extended spiral chain of units in a protein, nucleic acid, or other large molecule. The plural term is *helices.*

The Work of Watson and Crick While Franklin was continuing her research, James Watson, an American biologist, and Francis Crick, a British physicist, were also trying to understand the structure of DNA. They built three-dimensional models of the molecule that were made of cardboard and wire. They twisted and stretched the models in various ways, but their best efforts did nothing to explain DNA's properties.

Then, early in 1953, Watson was shown a copy of Franklin's remarkable X-ray pattern. The effect was immediate. In his book *The Double Helix*, Watson wrote: "The instant I saw the picture my mouth fell open and my pulse began to race."

Crick's original sketch of DNA

James Watson, at left, and Francis Crick with their model of a DNA molecule in 1953



A computer model of DNA

The clues in Franklin's X-ray pattern enabled Watson and Crick to build a model that explained the specific structure and properties of DNA. The pair published their results in a historic one-page paper in April of 1953, when Franklin's paper describing her X-ray work was also published. Watson and Crick's breakthrough model of DNA was a double helix, in which two strands of nucleotide sequences were wound around each other.

The Double-Helix Model

What does the double-helix model tell us about DNA?

A double helix looks like a twisted ladder. In the double-helix model of DNA, the two strands twist around each other like spiral staircases. Watson and Crick realized that the double helix accounted for Franklin's X-ray pattern. Further still, it explained many of the most important properties of DNA. **The double-helix model explains Chargaff's rule of base pairing and how the two strands of DNA are held together.** This model can even tell us how DNA can function as a carrier of genetic information.

Antiparallel Strands One of the surprising aspects of the double-helix model is that the two strands of DNA run in opposite directions. In the language of biochemistry, these strands are "antiparallel." This arrangement enables the nitrogenous bases on both strands to come into contact at the center of the molecule. It also allows each strand of the double helix to carry a sequence of nucleotides, arranged almost like letters in a four-letter alphabet.

In Your Notebook *Draw and label your own model of the DNA double-helix structure.*

MYSTERY CLUE

Our skin cells are exposed to UV light whenever they are in direct sunlight. How might this exposure affect base pairing in the DNA of our skin cells?

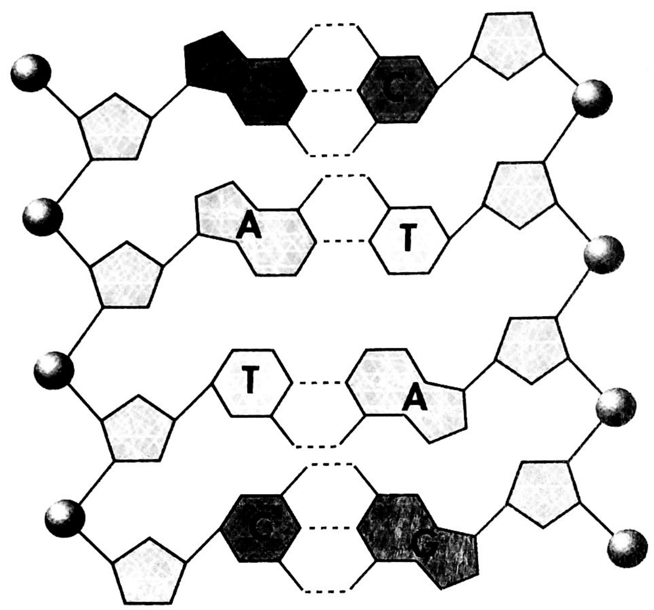


FIGURE 12–7 Base Pairing The two strands of DNA are held together by hydrogen bonds between the nitrogenous bases adenine and thymine, and between guanine and cytosine.

Hydrogen Bonding At first, Watson and Crick could not explain what forces held the two strands of DNA's double helix together. They then discovered that hydrogen bonds could form between certain nitrogenous bases, providing just enough force to hold the two strands together. As you may recall, hydrogen bonds are relatively weak chemical forces.

Does it make sense that a molecule as important as DNA should be held together by weak bonds? Indeed, it does. If the two strands of the helix were held together by strong bonds, it might well be impossible to separate them. As we will see, the ability of the two strands to separate is critical to DNA's functions.

Base Pairing Watson and Crick's model showed that hydrogen bonds could create a nearly perfect fit between nitrogenous bases along the center of the molecule. However, these bonds would form only between certain base pairs—adenine with thymine, and guanine with cytosine. This nearly perfect fit between A–T and G–C nucleotides is known as **base pairing,** and is illustrated in **Figure 12–7.**

Once they observed this process, Watson and Crick realized that base pairing explained Chargaff's rule. It gave a reason why [A] = [T] and [G] = [C]. For every adenine in a double-stranded DNA molecule, there has to be exactly one thymine. For each cytosine, there is one guanine. The ability of their model to explain Chargaff's observations increased Watson and Crick's confidence that they had come to the right conclusion, with the help of Rosalind Franklin.

12.2 Assessment

Review Key Concepts

1. a. Review List the chemical components of DNA.

b. Relate Cause and Effect Why are hydrogen bonds so essential to the structure of DNA?

2. a. Review Describe the discoveries that led to the modeling of DNA.

b. Infer Why did scientists have to use tools other than microscopes to solve the structure of DNA?

3. a. Review Describe Watson and Crick's model of the DNA molecule.

b. Apply Concepts Did Watson and Crick's model account for the equal amounts of thymine and adenine in DNA? Explain.

VISUAL THINKING

4. Make a three-dimensional model showing the structure of a DNA molecule. Your model should include the four base pairs that help form the double helix.