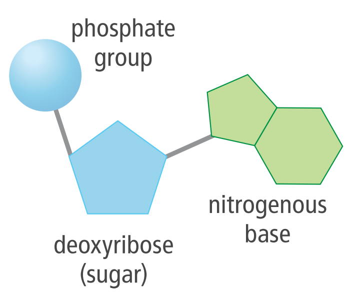
The Structure of DNA

Once Hershey and Chase completed their experiments with bacteriophages, it was clear that DNA was responsible for the inheritance of traits. What scientists did not yet understand, however, was how DNA stored genetic information. To understand this, they first needed to understand the molecular structure of DNA.

Nucleotides

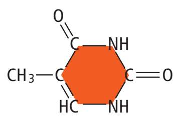
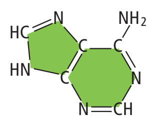
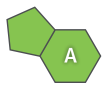
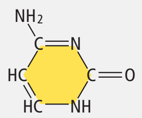
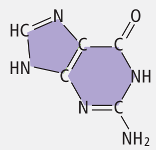
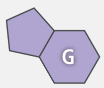
Scientists have known since the 1920s that the DNA molecule is a very long polymer, or chain of repeating subunits. The subunit, or monomer, that makes up DNA is called a nucleotide, shown in Figure 7.

FIGURE 7: Nucleotide Structure



One molecule of human DNA contains billions of nucleotides. However, if you were to divide all of those nucleotides into groups of identical nucleotides, you would end up with just four groups. The nucleotides that make up DNA differ only in their nitrogen–containing, or nitrogenous, bases. The bases are cytosine (C), thymine (T), adenine (A), and guanine (G). The letter abbreviations refer both to the bases and to the nucleotides that contain the bases.

FIGURE 8: The four nucleotides that make up DNA

PYRIMIDINES			PURINES		
Name of base	Structural formula	Model	Name of base	Structural formula	Model
thymine			adenine		
cytosine			guanine		

Explain Use the information in Figure 8 to answer the following questions.

1. How do the structures of purines differ from the structures of pyrimidines?
2. Which base is most similar in structure to thymine?

Determining DNA Structure

For a long time, scientists assumed that DNA was made up of equal amounts of the four nucleotides and that the DNA in all organisms was therefore exactly the same. That assumption made it difficult to convince scientists that DNA was the genetic material. They reasoned that identical molecules could not carry different instructions across all organisms. However, in 1950, Erwin Chargaff conducted a set of experiments that challenged this assumption.

Chargaff's Experiments

Chargaff changed the thinking about DNA by analyzing the DNA of several different organisms. He found that the same four bases are found in the DNA of all organisms, but the proportion of the four bases differs from one organism to another.

Data Analysis

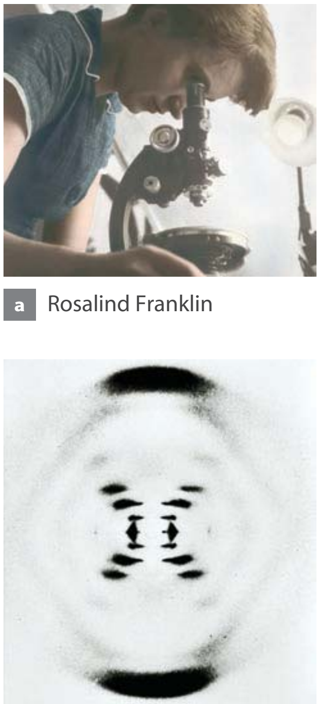
FIGURE 9: Nucleotide ratios leading to the formulation of Chargaff's rules

Source	Adenine to Guanine	Thymine to Cytosine	Adenine to Thymine	Guanine to Cytosine	Purines to Pyrimidines
Human	1.56	1.75	1.00	1.00	1.00
Chicken	1.45	1.29	1.06	0.91	0.99
Salmon	1.43	1.43	1.02	1.02	1.02
Wheat	1.22	1.18	1.00	0.97	0.99
Yeast	1.67	1.92	1.03	1.20	1.00
E-coli k2	1.05	0.95	1.09	0.99	1.00

Analyze

1. The numbers shown in the table are ratios. For example, the ratio of adenine to guanine in humans is 1.56 to 1, or 1.56:1. The 1 is assumed, and not shown. What do you observe about these ratios?
2. How does Chargaff's work support the idea that DNA is the molecule of inheritance?

FIGURE 10: X-ray Evidence



a Rosalind Franklin

b X-ray crystallography

Franklin's X-Ray Crystallography

In the early 1950s, British scientist Rosalind Franklin was studying DNA using a technique called x-ray crystallography. When crystallized DNA is bombarded with x-rays, the atoms 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. The pattern and angle of the *X* suggested that DNA consists of two strands, spaced at a consistent width apart and twisted into a helical shape.

Collaborate Rosalind Franklin's results made her think that the DNA molecule was a helical, or spiral, shape. With a partner, discuss what questions about the structure of DNA were not answered by her results.

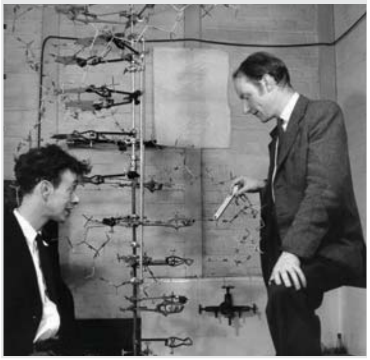
Watson and Crick's Model of DNA

At about the same time that Franklin was working with x-ray crystallography, American geneticist James Watson and British physicist Francis Crick were also studying DNA structure. Their interest was sparked by the earlier work of Hershey, Chase, and Chargaff as well as biochemist Linus Pauling. Pauling discovered that the structure of some proteins was a helix, or spiral. Watson and Crick hypothesized that DNA might also be a helix. Franklin's crystallographs, along with her calculations, gave them the clues they needed to develop models like the one shown in Figure 11.

Watson and Crick began working with their model to determine the structure of DNA. They knew they had to be able to twist their model to account for the evidence provided by Franklin's x-rays. They placed the sugar-phosphate backbones on the outside and the nitrogenous 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 made a helix that varied in width. This arrangement was not supported by Franklin's data, which showed that the width of the molecule was constant. Finally, Watson and Crick found that if they paired doubled-ringed nucleotides with single-ringed nucleotides, the bases fit like a puzzle.

In April 1953, Watson and Crick published their DNA model in the journal *Nature*. Working from Franklin's data, they built a double-helix model in which the two strands were complementary—that is, if one strand is ACACAC, the other strand is TGTGTG. The pairing of bases in their model supported Chargaff's results. These A–T and C–G relationships became known as Chargaff's rules.

FIGURE 11: James Watson (left) and Frances Crick (right) used a model to figure out the structure of DNA.

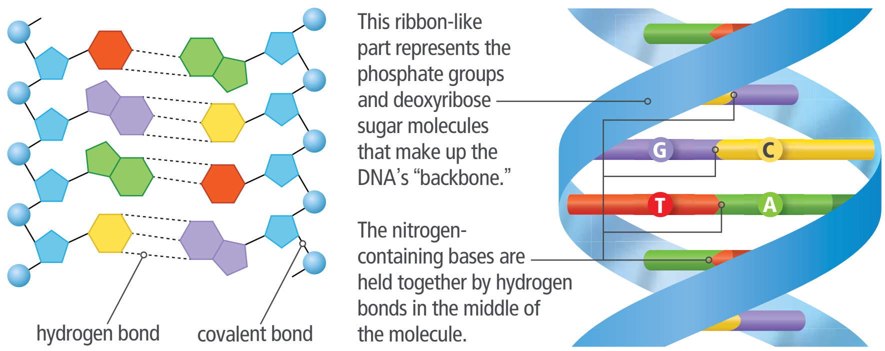


Analyze By building a physical model, Watson and Crick were able to see that adenine fit with thymine and guanine fit with cytosine. How do Chargaff's results support Watson and Crick's model?

Current DNA Model

As technology has advanced, our understanding of DNA has continually improved. The current model represents DNA nucleotides of a single strand 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, or the sugar-phosphate backbone of the molecule. 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.

FIGURE 12: Model of DNA



Predict Look at the hydrogen bonds between the base pairs in Figure 12. Which base pairs do you think are held more tightly together?

As Watson and Crick's model showed, the bases of the two DNA strands always follow Chargaff's rules for base pairing: 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—a purine is always paired with a pyrimidine—and the ability of the bases to form hydrogen bonds with each other. As an example of base pairing, if a sequence of bases on one strand of DNA is CTGCTA, the matching DNA strand will be GACGAT.

Model Describe the structure of DNA using a ladder as an analogy. What makes up the rungs, or steps, of the ladder? What makes up the sides? How is the ladder shaped?