12–1 DNA

How do genes work? What are they made of, and how do they determine the characteristics of organisms? Are genes single molecules, or are they longer structures made up of many molecules? In the middle of the 1900s, questions like these were on the minds of biologists everywhere.

To truly understand genetics, biologists first had to discover the chemical nature of the gene. If the structures that carry genetic information could be identified, it might be possible to understand how genes control the inherited characteristics of living things.

Griffith and Transformation

Like many stories in science, the discovery of the molecular nature of the gene began with an investigator who was actually looking for something else. In 1928, British scientist Frederick Griffith was trying to figure out how bacteria make people sick. More specifically, Griffith wanted to learn how certain types of bacteria produce a serious lung disease known as pneumonia.

Griffith had isolated two slightly different strains, or types, of pneumonia bacteria from mice. Both strains grew very well in culture plates in his lab, but only one of the strains caused pneumonia. The disease-causing strain of bacteria grew into smooth colonies on culture plates, whereas the harmless strain produced colonies with rough edges. The differences in appearance made the two strains easy to distinguish.

Guide for Reading

Key Concepts
- What did scientists discover about the relationship between genes and DNA?
- What is the overall structure of the DNA molecule?

Vocabulary
transformation
bacteriophage
nucleotide
base pairing

Reading Strategy: Summarizing As you read, find the key ideas for the text under each blue heading. Write down a few key words from each main idea. Then, use the key words in your summary. Revise your summary, keeping only the most important ideas.

Figure 12–1 White mice like these are commonly used in scientific experiments.

SECTION RESOURCES

TIME SAVER

Print:
- ***Laboratory Manual A,*** Chapter 12 Lab
- ***Laboratory Manual B,*** Chapter 12 Lab
- ***Teaching Resources,*** Section Review 12–1, Enrichment
- ***Reading and Study Workbook A,*** Section 12–1
- ***Adapted Reading and Study Workbook B,*** Section 12–1
- ***Biotechnology Manual,*** Labs 4, 5, 6
- ***Lesson Plans,*** Section 12–1

Technology:
- ***iText,*** Section 12–1
- ***Animated Biological Concepts Videotape Library,*** 20
- ***Transparencies Plus,*** Section 12–1
- ***Lab Simulations CD-ROM,*** DNA Structure and Replication

Section 12–1

1 FOCUS

Objectives

12.1.1 ***Summarize*** the relationship between genes and DNA.
12.1.2 ***Describe*** the overall structure of the DNA molecule.

Guide for Reading

Vocabulary Preview

Read the Vocabulary terms aloud to the class. Then, invite students to write the words and divide them into syllables as best they can. The correct syllabications are trans•for•ma•tion, bac•te•ri•o•phage, nu•cle•o•tide, base pair•ing.

Reading Strategy

Before students read the section, have them write a question for each of the section heads. As they read for key ideas to summarize the section, they should also write the answers to their questions.

2 INSTRUCT

Griffith and Transformation

Build Science Skills

Asking Questions Engage students in a discussion about the scientific question that Griffith originally set out to answer. Explain that Griffith set out to learn whether or not a toxin produced by the bacteria was the cause of pneumonia. Brainstorm a list of scientific questions that Griffith might have asked when he designed his experiment. Write the questions on the board. Work together as a class to decide which questions could serve as the basis for scientific inquiry and which could not. L2

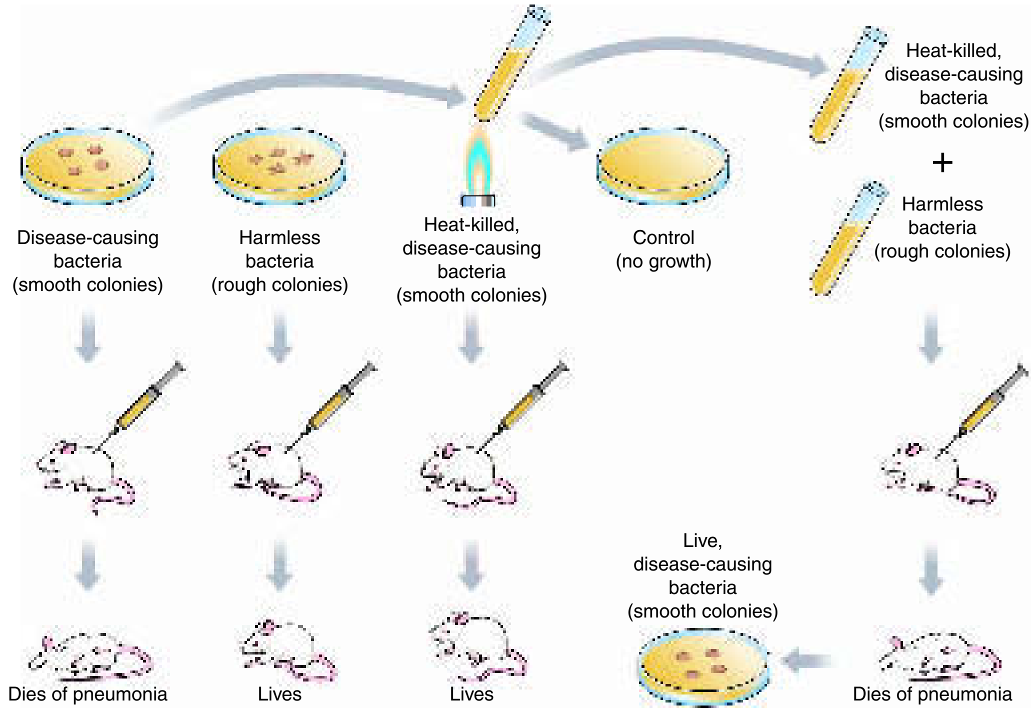
12–1 (continued)

Use Visuals

Figure 12–2 Review Griffith's transformation experiment. Ask: **What was Griffith trying to learn when he set up this experiment?** *(How bacteria caused pneumonia)* Encourage students to evaluate Griffith's experimental design and discuss the controls he used. Then, ask: **How did Griffith show that the disease-causing bacteria were killed by the heat?** *(He tried to grow them in a petri dish. If the bacteria grew, then he knew that he had not killed them.)* **What result was Griffith expecting when he injected the mixture of live harmless bacteria and heat-killed disease-causing bacteria?** *(He expected the mice to live.)* L2

Make Connections

Health Science Poll the class to find out who remembers getting immunizations for tetanus and diphtheria. Find out if anyone knows why he or she received the immunizations and how they work. Explain that for these diseases, the immunizations are actually toxoids, or inactivated toxins. These diseases are not caused by the bacteria themselves but by toxins that the bacteria produce. Ask: **Why do you think it's important to learn how bacteria cause disease?** *(To find a cure for the disease or a means to prevent it)* Explain that Griffith set up his experiment to show that a toxin produced by the bacteria causes pneumonia. It was later learned that pneumonia is caused instead by bacterial growth damaging healthy lung tissue. L2



▲ **Figure 12–2** Griffith injected mice with four different samples of bacteria. When injected separately, neither heat-killed, disease-causing bacteria nor live, harmless bacteria killed the mice. The two types injected together, however, caused fatal pneumonia. From this experiment, biologists inferred that genetic information could be transferred from one bacterium to another. **Inferring** ***After heating the disease-causing bacteria, why did Griffith test whether material from the bacterial culture would produce new colonies in a petri dish?***

Griffith's Experiments When Griffith injected mice with the disease-causing strain of bacteria, the mice developed pneumonia and died. When mice were injected with the harmless strain, they didn't get sick at all. Griffith wondered if the disease-causing bacteria might produce a poison.

To find out, he took a culture of these cells, heated the bacteria to kill them, and injected the heat-killed bacteria into mice. The mice survived, suggesting that the cause of pneumonia was not a chemical poison released by the disease-causing bacteria. Griffith's experiments are shown in **Figure 12–2.**

Transformation Griffith's next experiment produced an amazing result. He mixed his heat-killed, disease-causing bacteria with live, harmless ones and injected the mixture into mice. By themselves, neither should have made the mice sick. But to Griffith's amazement, the mice developed pneumonia and many died. When he examined the lungs of the mice, he found them filled not with the harmless bacteria, but with the disease-causing bacteria. Somehow the heat-killed bacteria had passed their disease-causing ability to the harmless strain. Griffith called this process **transformation** because one strain of bacteria (the harmless strain) had apparently been changed permanently into another (the disease-causing strain).

Differentiated Instruction — Solutions for All Learners

Less Proficient Readers Students can review the vocabulary of DNA structure by making a concept map that includes the terms *nucleotide, deoxyribose, phosphate group, nitrogenous base, purine, pyrimidine, adenine, guanine, cytosine,* and *thymine.* L1

English Language Learners Have students assemble a glossary of terms for this chapter. They can include phonetic spellings of words and definitions in their own words. Use synonyms or mnemonics to help with meanings. Students can also use illustrations and phrases from their native languages. L1 L2

Advanced Learners Students might enjoy reading *The Double Helix: A Personal Account of the Discovery of the Structure of DNA* by James Watson, and *Rosalind Franklin: The Dark Lady of DNA* by Brenda Maddox. Invite students to discuss the books and their characters. L2 L3

Griffith hypothesized that when the live, harmless bacteria and the heat-killed bacteria were mixed, some factor was transferred from the heat-killed cells into the live cells. That factor, he hypothesized, must contain information that could change harmless bacteria into disease-causing ones. Furthermore, since the ability to cause disease was inherited by the transformed bacteria's offspring, the transforming factor might be a gene.

Avery and DNA

In 1944, a group of scientists led by Canadian biologist Oswald Avery at the Rockefeller Institute in New York decided to repeat Griffith's work. They did so to determine which molecule in the heat-killed bacteria was most important for transformation. If transformation required just one particular molecule, that might well be the molecule of the gene.

Avery and his colleagues made an extract, or juice, from the heat-killed bacteria. They then carefully treated the extract with enzymes that destroyed proteins, lipids, carbohydrates, and other molecules, including the nucleic acid RNA. Transformation still occurred. Obviously, since these molecules had been destroyed, they were not responsible for the transformation.

Avery and the other scientists repeated the experiment, this time using enzymes that would break down DNA. When they destroyed the nucleic acid DNA in the extract, transformation did not occur. There was just one possible conclusion. DNA was the transforming factor. **Avery and other scientists discovered that the nucleic acid DNA stores and transmits the genetic information from one generation of an organism to the next.**

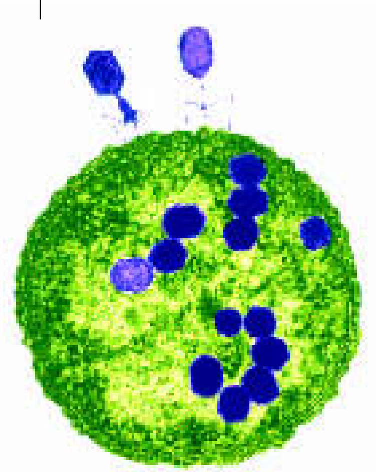
The Hershey-Chase Experiment

Scientists are a skeptical group. It usually takes several experiments to convince them of something as important as the chemical nature of the gene. The most important of these experiments was performed in 1952 by two American scientists, Alfred Hershey and Martha Chase. They collaborated in studying viruses, nonliving particles smaller than a cell that can infect living organisms.

Bacteriophages One kind of virus that infects bacteria is known as a **bacteriophage** (bak-TEER-ee-uh-fayj), which means "bacteria eater." **Figure 12–3** shows typical bacteriophages. Bacteriophages are composed of a DNA or RNA core and a protein coat. When a bacteriophage enters a bacterium, the virus attaches to the surface of the cell and injects its genetic information into it. The viral genes act to produce many new bacteriophages, and they gradually destroy the bacterium. When the cell splits open, hundreds of new viruses burst out.

CHECKPOINT *What is a bacteriophage?*

▼ **Figure 12–3** A bacteriophage is a type of virus that infects and kills bacteria. This image shows two T2 bacteriophages (purple) invading an *E. coli* cell (green). **Comparing and Contrasting** *How large are viruses compared with bacteria?*



(magnification: 25,000×)

Avery and DNA

Build Science Skills

Designing Experiments Challenge students to diagram the experiments conducted by Avery and his group to repeat Griffith's work. Students should identify the variable in the experiment. *(The enzyme used to destroy a certain molecule)* Make sure students realize that Avery used only one enzyme at a time. Explain that for these experiments, they didn't need mice because they had developed a test for the presence of transformed bacterial cells that could be done in a test tube. Ask: **How did this experiment show that it was DNA and not any other molecule?** *(Transformation occurred every time, except when DNA was destroyed.)* L2

The Hershey-Chase Experiment

Demonstration

Diagram on the board the process by which a bacteriophage infects and replicates in bacteria. Show how the bacteriophage injects its DNA into a bacterium and how DNA incorporates itself into the bacterial DNA (which is usually circular). Explain that the bacterium is tricked into thinking that the viral DNA is its own and begins to make the bacteriophage's DNA and proteins. These parts assemble into new bacteriophages and burst out of the bacterial cell, killing it in the process. If possible, find electron micrographs of this process to show to students. L1 L2

BIO INSIGHTS — **HISTORY OF SCIENCE**

Scientists are a skeptical bunch
Today, Avery's results show without a doubt that DNA makes up genes. However, in 1944 the results were questionable. Then, inheritance in bacteria was just beginning to be studied. Scientists didn't know if bacteria had genes like those in more complex organisms. And even if DNA were the hereditary substance in bacteria, it might not be the hereditary substance in more complex organisms. DNA was still considered a very simple molecule. Scientists were more excited about Hershey and Chase's results with bacteriophages in 1952. By that time, genetic studies showed that bacteriophages had properties of heredity similar to those of more complex organisms. Also, experiments showed that DNA was more complex than originally thought.

Answers to . . .

CHECKPOINT *A virus that infects and kills bacteria*

Figure 12–2 *If the bacteria grew, then he knew that he had not killed them.*

Figure 12–3 *Viruses are smaller.*

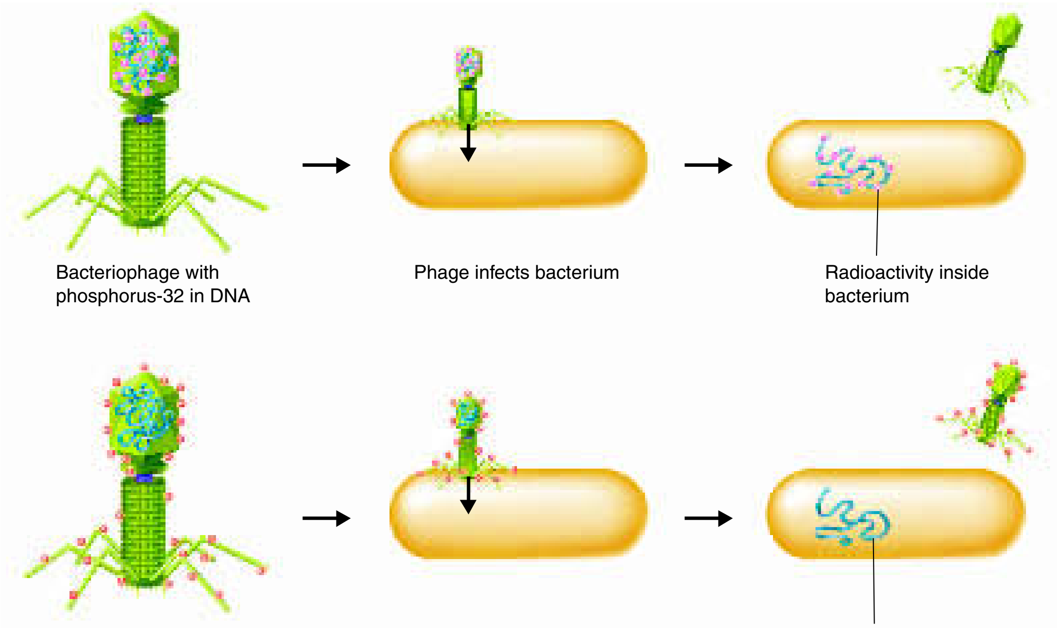
12–1 (continued)

Use Visuals

Figure 12–4 Use the diagram to discuss Hershey and Chase's experimental design. Make sure students understand that the radioactive elements can be easily observed in the laboratory. Ask: **How were Hershey and Chase able to determine whether bacteriophages injected DNA or protein into bacteria?** *(By growing the bacteriophages in cultures containing either ^{32}P or ^{35}S so that the bacteriophage DNA—which contains phosphorus—or protein—which contains sulfur—would be labeled in a way that was easy to follow)* **What would you expect if a bacteriophage injected protein into a bacterial cell?** *(If the bacteriophage injected protein, the bacterial cell would contain ^{35}S. If it injected DNA, it would contain ^{32}P.)* L2

Make Connections

Chemistry Explain that radioactive elements are unstable isotopes of an element. Diagram an atom of hydrogen on the board with one proton in the nucleus and one electron. Add one neutron to the nucleus. Ask: **Now what element is this?** *(It's still hydrogen, but it is an isotope of hydrogen, deuterium.)* Add another neutron to the nucleus, and ask a volunteer to tell what element it is now. *(Another hydrogen isotope, tritium)* Point out that the three isotopes of hydrogen all have the same chemical properties—they each have one proton and one electron. However, they have very different physical properties because of their differences in mass. Ask: **What causes their mass to be different?** *(Neutrons)* **Do neutrons affect the chemical properties of an element?** *(No)* **Why not?** *(They are not charged particles; they do not repel or attract other particles.)* Explain that tritium is an unstable, radioactive isotope because its nucleus tends to break down and release small particles of energy. This release of energy is called radioactivity. L2 L3



▲ **Figure 12–4** Alfred Hershey and Martha Chase used different radioactive markers to label the DNA and proteins of bacteriophages. The bacteriophages injected only DNA into the bacteria, not proteins. **From these results, Hershey and Chase concluded that the genetic material of the bacteriophage was DNA.**

Radioactive Markers Hershey and Chase reasoned that if they could determine which part of the virus—the protein coat or the DNA core—entered the infected cell, they would learn whether genes were made of protein or DNA. To do this, they grew viruses in cultures containing radioactive isotopes of phosphorus-32 (^{32}P) and sulfur-35 (^{35}S). This was a clever strategy because proteins contain almost no phosphorus and DNA contains no sulfur. The radioactive substances could be used as markers. If ^{35}S was found in the bacteria, it would mean that the viruses' protein had been injected into the bacteria. If ^{32}P was found in the bacteria, then it was the DNA that had been injected.

The Hershey-Chase experiment is shown in **Figure 12–4.** The two scientists mixed the marked viruses with bacteria. Then, they waited a few minutes for the viruses to inject their genetic material. Next, they separated the viruses from the bacteria and tested the bacteria for radioactivity. Nearly all the radioactivity in the bacteria was from phosphorus (^{32}P), the marker found in DNA. **Hershey and Chase concluded that the genetic material of the bacteriophage was DNA, not protein.**

CHECKPOINT *What part of the virus did the Hershey-Chase experiment show had entered the bacteria?*

BIO INSIGHTS

FACTS AND FIGURES

Radioisotopes—a tool for biologists
Biologists commonly use radioisotopes—radioactive isotopes—to learn about cell processes, because they can be substituted into biochemical reactions without changing the chemistry of the reaction. Radioactive isotopes are unstable and break apart or "decay" into a stable form. Because of this decay, their presence can be detected. When they decay, two different kinds of particles are given off—alpha particles, which are 2 neutrons and 2 protons, and beta particles, which are high-speed electrons. In some cases, gamma rays are also given off. Gamma rays are electromagnetic waves of energy that act like X-rays. All forms of radiation, but especially gamma rays, can damage tissues.

The Components and Structure of DNA

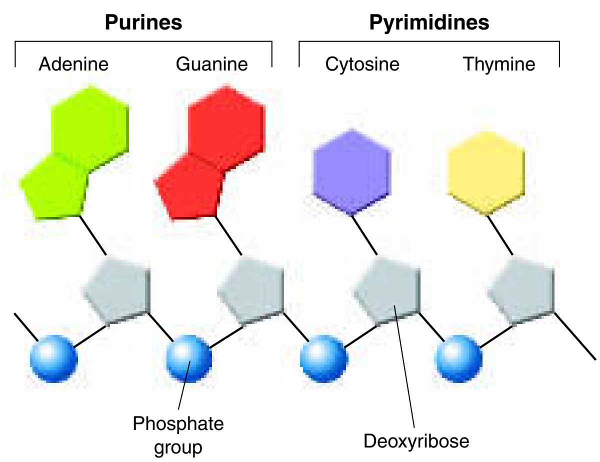
You might think that knowing genes were made of DNA would have satisfied scientists, but that was not the case at all. Instead, they wondered how DNA, or any molecule for that matter, could do the three critical things that genes were known to do: First, genes had to carry information from one generation to the next; second, they had to put that information to work by determining the heritable characteristics of organisms; and third, genes had to be easily copied, because all of a cell's genetic information is replicated every time a cell divides. For DNA to do all of that, it would have to be a very special molecule indeed.

DNA is a long molecule made up of units called **nucleotides.** As **Figure 12–5** shows, each nucleotide is made up of three basic components: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous (nitrogen-containing) base. There are four kinds of nitrogenous bases in DNA. Two of the nitrogenous bases, adenine (AD-uh-neen) and guanine (GWAH-neen), belong to a group of compounds known as purines. The remaining two bases, cytosine (SY-tuh-zeen) and thymine (THY-meen), are known as pyrimidines. Purines have two rings in their structures, whereas pyrimidines have one ring.

The backbone of a DNA chain is formed by sugar and phosphate groups of each nucleotide. The nitrogenous bases stick out sideways from the chain. The nucleotides can be joined together in any order, meaning that any sequence of bases is possible.

If you don't see much in **Figure 12–5** that could explain the remarkable properties of the gene, 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 ways, so it was possible they could carry coded genetic information. However, so could many other molecules, at least in principle. Was there something more to the structure of DNA?

Go Online NSTA SCILINKS
For: Links on DNA
Visit: www.SciLinks.org
Web Code: cbn-4121



◀ **Figure 12–5** DNA is made up of nucleotides. Each nucleotide has three parts: a deoxyribose molecule, a phosphate group, and a nitrogenous base. There are four different bases in DNA: adenine, guanine, cytosine, and thymine. **Interpreting Graphics** ***How are the nucleotides joined together to form the DNA chain?***

TEACHER TO TEACHER

Students often have difficulty understanding how a nucleic acid such as DNA is constructed, even after viewing models or laserdisc presentations. The idea "clicks," however, when they're allowed to construct a nucleic acid from the members of the class in an activity we do outside of the classroom. Students are assigned a specific nitrogenous base and must pair with their complementary base until the DNA molecule is replicated. I also use the activity to teach the different kinds of bonds in DNA and the workings of enzymes such as DNA polymerase. Students really get to understand DNA from this experience, and most of all, they have fun doing the project.

—Leon Lange
Biology Teacher
Fort Campbell High School
Fort Campbell, KY

The Components and Structure of DNA

Go Online NSTA SCILINKS
Download a worksheet on DNA for students to complete, and find additional teacher support from NSTA SciLinks.

Build Science Skills

Predicting Challenge students to predict how DNA is able to carry out the three critical things that genes are known to do. Have them write their predictions in their lab manuals. When you complete the chapter, have students check their predictions to see if they are correct. Encourage students to share the facts or inferences on which they based their predictions. L2 L3

Demonstration

Demonstrate what a polymer is by linking together paper clips to make a chain. Explain that a polymer is a very large molecule made up of repeating units that are bonded together. The individual paper clips act as the repeating units of the polymer chain. You can make the polymer chain more complex by making the repeating unit more complex, for example, by adding beads or safety pins to the paper clips. Ask: **How many basic units does DNA have?** *(Three: deoxyribose, a phosphate group, and a nitrogenous base)* Explain that polymers can be very strong and flexible and have a variety of uses. For example, nylon is a polymer. L1 L2

Answers to . . .

CHECKPOINT *The DNA*

Figure 12–5 *By the deoxyribose sugar and the phosphate group*

12–1 (continued)

Biology and History

Tell students that the DNA and RNA molecules were discovered not long after Mendel published his ideas about inheritance. Discuss how long it was before scientists made the connection between DNA and genes and why it took so long to establish the molecular basis of inheritance. Then, focus on the short period of time between Avery's work and Watson and Crick's proposal for the DNA molecule.

Writing in Science

Students' essays should describe the research activities of James Watson or Francis Crick since the early 1950s. They might write something similar to a time line, or they might write a summary. Students should mention what the scientist they choose is doing now. L2

Percentages of Bases in Four 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

▲ **Figure 12–6** Erwin Chargaff showed that the percentages of guanine and cytosine in DNA are almost equal. The same is true for adenine and thymine. **Interpreting Graphics** ***Which organism has the highest percentage of adenine?***

Chargaff's Rules One of the puzzling facts about DNA was a curious relationship between its nucleotides. Years earlier, Erwin Chargaff, an American biochemist, had discovered that the percentages of guanine [G] and cytosine [C] bases are almost equal in any sample of DNA. The same thing is true for the other two nucleotides, adenine [A] and thymine [T], as shown in **Figure 12–6.** The observation that [A] = [T] and [G] = [C] became known as Chargaff's rules. 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.

X-Ray Evidence In the early 1950s, a British scientist named Rosalind Franklin began to study DNA. She used a technique called X-ray diffraction to get information about the structure of the DNA molecule. Aiming a powerful X-ray beam at concentrated DNA samples, she recorded the scattering pattern of the X-rays on film. Franklin worked hard to make better and better patterns from DNA until the patterns became clear.

Biology and History

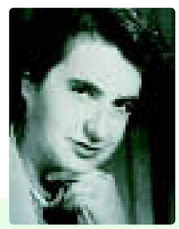
Discovering the Role of DNA

Genes and the laws of heredity were discovered before scientists identified the molecules that genes are made of. With the discovery of DNA, scientists have been able to explain how genes are replicated and how they function.

1928
Frederick Griffith
Griffith discovers that a factor in heat-killed, disease-causing bacteria can "transform" harmless bacteria into ones that can cause disease.

1944
Oswald Avery
Avery's team determines that genes are composed of DNA.

1951
Linus Pauling
Robert Corey
Pauling and Corey determine that the structure of a class of proteins is a helix.



1952
Rosalind Franklin
Franklin studies the DNA molecule using a technique called X-ray diffraction.

1900 1925 1950

BIO INSIGHTS — HISTORY OF SCIENCE

Watson and Crick's discoveries
When Watson and Crick were ready to announce their double-helix model in 1953, they made drawings of DNA and sent their paper to *Nature* magazine. They ended their first paper by writing, "It has not escaped our notice that the specific pairing we have postulated immediately suggests a possible copying mechanism for the genetic material." Within a few weeks, Watson and Crick had written another paper describing the copying mechanism.

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 in the photograph in the time line 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 molecule.

CHECKPOINT *What technique did Franklin use to study DNA?*

The Double Helix At the same time that Franklin was continuing her research, Francis Crick, a British physicist, and James Watson, an American biologist, were trying to understand the structure of DNA by building three-dimensional models of the molecule. Their models 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." Using clues from Franklin's pattern, within weeks Watson and Crick had built a structural model that explained the puzzle of how DNA could carry information, and how it could be copied. They published their results in a historic one-page paper in April of 1953. **Watson and Crick's model of DNA was a double helix, in which two strands were wound around each other.**

Writing in Science

Do research in the library or on the Internet to find out what James Watson or Francis Crick has worked on since discovering the structure of DNA. Organize your findings about the scientist's work and write a short essay describing it.

1953
James Watson
Francis Crick
Watson and Crick develop the double-helix model of the structure of DNA.

1960
Sydney Brenner
Brenner and other scientists show the existence of messenger RNA.

1977
Walter Gilbert
Gilbert, Allan Maxam, and Frederick Sanger develop methods to read the DNA sequence.

2000
Human Genome Project
The Human Genome Project—an attempt to sequence all human DNA—is essentially complete.

1950 1975 2000

Build Science Skills

Using Models Make available various materials for building models of the DNA molecule. You might provide pipe cleaners, an assortment of beads, and small foam balls. Encourage student groups to use the materials to build a model of the DNA molecule. They may use the illustration in Figure 12–7 as a guide. Help students see that the structure is like a twisted ladder. Make sure they understand that this structure is called a helix. DNA is a double helix because it has two strands, like the two rails of a ladder. L1 L2

Answers to . . .

CHECKPOINT *X-ray diffraction*

Figure 12–6 *Yeast*

12–1 (continued)

Use Visuals

Figure 12–7 As students study the diagram, point out that the dotted lines represent the hydrogen bonds that hold together the two DNA strands. Ask: **How does the arrangement of base pairs relate to Chargaff's rules?** *(Adenine and thymine are present in equal percentages because the two bases always pair together; guanine and cytosine are present in equal percentages because they always pair together.)* L2

3 ASSESS

Evaluate Understanding

Devise a question-and-answer game for the class in which teams of three or four students work together to answer questions about the discovery of DNA and its structure.

Reteach

Encourage students to draw their own diagram of the DNA molecule using Figure 12–7 as a guide. Students should label all parts of the molecule.

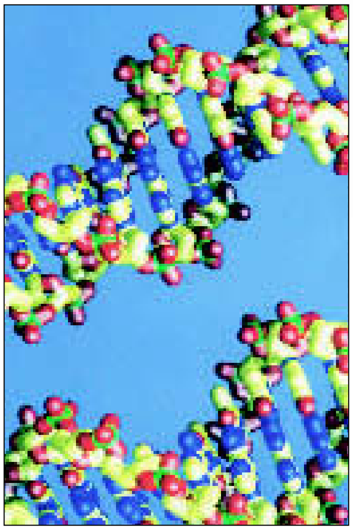
Connecting Concepts

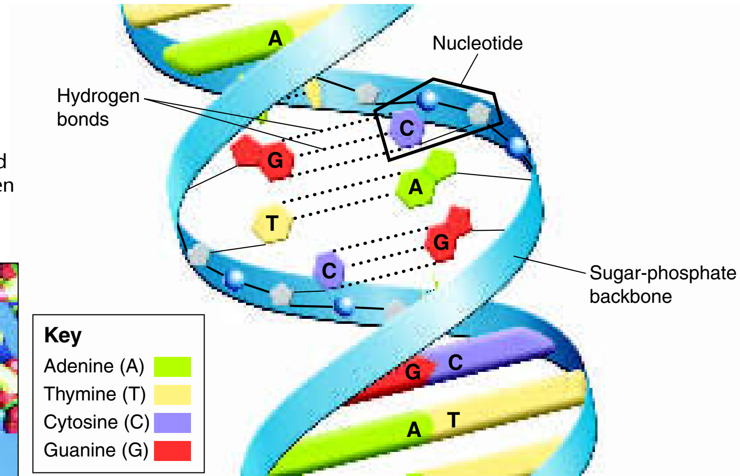
Students can choose the experiments of Griffith, Avery, or Hershey and Chase for their flowcharts. You might divide the class into thirds to ensure that each experiment is covered. Organizers should include the procedure and the conclusions of each experiment.

Interactive Textbook

If your class subscribes to the iText, use it to review the Key Concepts in Section 12–1.

Figure 12–7 **DNA is a double helix in which two strands are wound around each other.** Each strand is made up of a chain of nucleotides. The two strands are held together by hydrogen bonds between adenine and thymine and between guanine and cytosine.





A double helix looks like a twisted ladder or a spiral staircase. When Watson and Crick evaluated their DNA model, they realized that the double helix accounted for many of the features in Franklin's X-ray pattern but did not explain what forces held the two strands together. They then discovered that hydrogen bonds could form between certain nitrogenous bases and provide just enough force to hold the two strands together. As **Figure 12–7** shows, hydrogen bonds can form only between certain base pairs—adenine and thymine, and guanine and cytosine. Once they saw this, they realized that this principle, called **base pairing,** explained Chargaff's rules. Now there was a reason that [A] = [T] and [G] = [C]. For every adenine in a double-stranded DNA molecule, there had to be exactly one thymine molecule; for each cytosine molecule, there was one guanine molecule.

12–1 Section Assessment

1. **Key Concept** List the conclusions Griffith, Avery, Hershey, and Chase drew from their experiments.
2. **Key Concept** Describe Watson and Crick's model of the DNA molecule.
3. What are the four kinds of bases found in DNA?
4. Did Watson and Crick's model account for the equal amounts of thymine and adenine in DNA? Explain.
5. **Critical Thinking Inferring** Why did Hershey and Chase grow viruses in cultures that contained both radioactive phosphorus and radioactive sulfur? What might have happened if they had used only one radioactive substance?

Connecting Concepts

Scientific Methods
Using the experiments of Griffith, Avery, or Hershey and Chase as an example, develop a flowchart that shows how the scientist or scientists used scientific processes. Be sure to identify each process. *Hint*: You may wish to review Chapter 1, which describes scientific methods.

12–1 Section Assessment

1. Griffith and Avery: genes were probably made of DNA; Hershey and Chase: genetic material of bacteriophage was DNA, not protein.
2. DNA is a double helix in which two strands are wound around each other.
3. Adenine, thymine, guanine, cytosine
4. Yes; hydrogen bonds can form only between certain base pairs—adenine with thymine and guanine with cytosine.
5. So that both the viral DNA and viral proteins would be marked; either they would not have been able to trace the location of the unmarked molecule in the bacterial cell, or the results would not have been conclusive.