Connect to the Big Idea

Ask students to describe the sculpture shown on this page. (Sample answer: circular, twisted, colorful) Point out the caption, which explains that this sculpture models the structure of DNA, a molecule that carries genetic information in living things.

Explain that the structure of DNA was not determined until the 1950s. Tell students that an understanding of DNA’s function gave some clues to its structure. Observations and experiments by many scientists also provided clues to DNA’s structure. Suggest students note the relationship between DNA’s structure and function as they read the chapter. Ask them to anticipate the answer to the question, What is the structure of DNA, and how does it function in genetic inheritance?

Have students read the Chapter Mystery. Ask them to make predictions about the relationship between UV light, cell damage, and skin cancer. After students have completed the chapter, have them compare their predictions to the information in the Chapter Mystery clues found throughout the chapter and online.

Have students preview the chapter vocabulary terms using the Flash Cards.

NATIONAL SCIENCE EDUCATION STANDARDS

UNIFYING CONCEPTS AND PROCESSES
I, II, V

CONTENT
C.1.c, C.2.a, C.2.c, G.1, G.2, G.3

INQUIRY
A.1.b, A.1.c, A.1.d, A.2.a, A.2.b, A.2.c, A.2.d, A.2.e, A.2.f

Understanding by Design

In Chapter 12, students learn about experiments that helped reveal the structure and function of DNA as well as how DNA replicates. Use the ideas and questions shown in the graphic organizer at the right to connect Chapter 12 content with the Unit 4 Enduring Understanding: DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

PERFORMANCE GOALS
Students’ mastery of Chapter 12 content will be demonstrated by their responses to discussion questions found in this Teacher’s Edition and their completion of labs and data analysis activities. Additionally, the Performance Tasks require students to synthesize with chapter content by creating a chapter review software presentation and writing a letter from the point of view of Watson or Crick.
This sculpture, outside the Lawrence Hall of Science at the University of California at Berkeley, models the structure of DNA—the substance that genes are made of.

UV LIGHT
“Put on your sunscreen!” This familiar phrase can be heard at most beaches on a sunny day. It’s an important directive, though, because sunlight—for all its beneficial effects—can readily damage the skin. The most dangerous wavelengths of sunlight are the ones we can’t see: the ultraviolet (UV) region of the electromagnetic spectrum. Not only can excess exposure to UV light damage skin cells, it can cause a deadly form of skin cancer that kills nearly 10,000 Americans each year. Why is UV light so dangerous? How can these particular wavelengths of light damage our cells to the point of causing cell death and cancer? As you read this chapter, look for clues to help you solve the question of why UV light is so damaging to skin cells. Then, solve the mystery.

Never Stop Exploring Your World.
Finding the connection between UV light and DNA is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where the mystery leads.

Chapter 12 EQ: What is the structure of DNA, and how does it function in genetic inheritance?

12.1 GQ: How did scientists determine that DNA is responsible for storing, copying, and transmitting genetic information?

12.2 GQ: How was the basic structure of DNA discovered?

12.3 GQ: How do cells copy their DNA?

What’s Online
Extend your reach by using these and other digital assets offered at Biology.com.

CHAPTER MYSTERY
Students collect information about how UV light changes DNA and how DNA damage causes skin cancer to help them solve the mystery.

UNTAMED SCIENCE VIDEO
Follow the Untamed Science crew as they unlock the hidden information that can be found in DNA evidence from a crime scene.

ART IN MOTION
Students can watch an animated version of the experiment that convinced scientists DNA was the genetic material found in cells.

VISUAL ANALOGY
With this activity, students will watch the ways in which DNA can be compared to a “How-To” book.

DATA ANALYSIS
Students can analyze DNA data to assess the relatedness of different species.

TUTOR TUBE
This online tutorial offers some handy strategies for remembering which DNA bases pair together.

INTERACTIVE ART
Students can watch an animation of DNA replication and then drag-and-drop labels to test their understanding.

DATA ANALYSIS
Students analyze DNA sequences for the purpose of identifying illegally caught whales.

ART REVIEW
This drag-and-drop labeling activity helps students review the differences between prokaryotic and eukaryotic DNA replication.
LESSON 12.1

Identifying the Substance of Genes

Getting Started

Objectives
12.1.1 Summarize the process of bacterial transformation.
12.1.2 Describe the role of bacteriophages in identifying genetic material.
12.1.3 Identify the role of DNA in heredity.

Student Resources
Study Workbooks A and B, 12.1 Worksheets
Spanish Study Workbook, 12.1 Worksheets

Activate Prior Knowledge

Have several volunteers describe how the information they learned in elementary and middle school prepared them for the academic work they are now doing in high school. Point out that, without the skills they learned earlier in life, they would be unable to carry out high-school level work. Explain that scientific knowledge grows in a similar way. Tell students this lesson will describe experiments that laid the groundwork for current work in the scientific field of genetics.

Key Questions

What clues did bacterial transformation yield about the gene?
What role did bacterial viruses play in identifying genetic material?
What is the role of DNA in heredity?

Vocabulary
transformation bacteriophage

Flowchart
As you read this section, make a flowchart that shows how scientists came to understand the molecule known as DNA.

Think About It
How do genes work? To answer that question, the first thing you need to know is what genes are made of. After all, you couldn’t understand how an automobile engine works without understanding what the engine is made of and how it’s put together. So, how would you go about figuring out what molecule or molecules go into making a gene?

Bacterial Transformation

What clues did bacterial transformation yield about the gene?

In the first half of the twentieth century, biologists developed the field of genetics to the point where they began to wonder about the nature of the gene itself. To truly understand genetics, scientists realized they first had to discover the chemical nature of the gene. If the molecule that carries genetic information could be identified, it might be possible to understand how genes actually control the inherited characteristics of living things.

Like many stories in science, the discovery of the chemical nature of the gene began with an investigator who was actually looking for something else. In 1928, the 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 the serious lung disease known as pneumonia.

Griffith had isolated two very similar types of bacteria from mice. These were actually two different varieties, or strains, of the same bacterial species. Both strains grew very well in culture plates in Griffith’s lab, but only one of them caused pneumonia. The disease-causing bacteria (S strain) grew into smooth colonies on culture plates, whereas the harmless bacteria (R strain) produced colonies with rough edges. The difference in appearance made the two strains easy to tell apart.

Griffith’s Experiments

When Griffith injected mice with disease-causing bacteria, the mice developed pneumonia and died. When he injected mice with harmless bacteria, the mice stayed healthy. Griffith wondered what made the first group of mice get pneumonia. Perhaps the S-strain bacteria produced a toxin that made the mice sick? To find out, he ran the series of experiments shown in Figure 12–1. First, Griffith took a culture of the S strain, heated the cells to kill them, then injected the heat-killed bacteria into laboratory mice. The mice survived, suggesting that the cause of pneumonia was not a toxin from these disease-causing bacteria.

ENDURING UNDERSTANDING DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION How did scientists determine that DNA is responsible for storing, copying, and transmitting genetic information?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how scientists identified the genetic material in cells. Have students work in small groups to write a newspaper article describing the work of either Frederick Griffith, Oswald Avery, or Alfred Hershey and Martha Chase. Explain that newspaper articles usually provide answers to the following set of questions: Who? What? Where? When? and Why? Have each group share its completed newspaper article with the class.

Teach for Understanding

DEEPEN UNDERSTANDING The scientists who helped identify the genetic material were interested in how genes work. To help students think about the possible future of this line of research, ask: What are some ways researchers could use this knowledge to help people?

Unifying Concepts and Processes

II, V

Content
C.1.c, C.2.a, G.1, G.2, G.3

Inquiry
A.2.a, A.2.b, A.2.c, A.2.e, A.2.f
In Griffith’s next experiment, he mixed the heat-killed, S-strain bacteria with live, harmless bacteria from the R strain. This mixture he injected into laboratory mice. By themselves, neither type of bacteria should have made the mice sick. To Griffith’s surprise, however, the injected mice developed pneumonia, and many died. When he examined the lungs of these mice, he found them to be filled not with the harmless bacteria, but with the disease-causing bacteria. How could that happen if the S-strain cells were dead?

**Transformation** Something odd was going on in the lungs of the mice. The heat-killed S-strain bacteria somehow passed their disease-causing ability to the harmless bacteria. Griffith reasoned that, when he mixed the two types of bacteria together, some chemical factor transferred from the heat-killed cells of the S strain into the live cells of the R strain. This chemical compound, he hypothesized, must contain information that could change harmless bacteria into disease-causing ones. He called this process *transformation*, because one type of bacteria (the harmless form) had been changed permanently into another (the disease-causing form). Because the ability to cause disease was inherited by the offspring of the transformed bacteria, Griffith concluded that the transforming factor had to be a gene.

**In Your Notebook** Write a summary of Griffith’s experiments.

![Diagram of transformation experiment]

**FIGURE 12–1 Griffith’s Experiments** 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 strains injected together, however, caused fatal pneumonia. From this experiment, Griffith inferred that genetic information could be transferred from one bacterial strain to another. **Infer** Why did Griffith test to see whether the bacteria recovered from the sick mice in his last experiment would produce smooth or rough colonies in a petri dish?

**DIFFERENTIATED INSTRUCTION**

**ELL** Less Proficient Readers Have struggling readers use Figure 12–1 to learn about Griffith’s experiment. Point out and describe what happens in each vertical panel of the figure.

**Ask** In this experiment, which strain of bacteria caused disease? *(the S strain)*

**Ask** What happened when heat-killed S strain was injected into a mouse? *(It no longer caused disease.)*

**Ask** What happened when the heat-killed S strain was mixed with the harmless R-strain bacteria? *(The mouse got sick.)*

**Focus on ELL:** Extend Language

**INTERMEDIATE SPEAKERS** To understand the content of this lesson, students need a working knowledge of terms such as experiment, inferred, concluded, and observed. As students read about the experiments in this lesson, have them locate these terms in the text. Ask students to find a definition for each term in a dictionary and to practice pronouncing each term aloud.

**Answers**

**FIGURE 12–1** to determine whether the substance transferred from the heat-killed bacteria to the R strain was heritable

**IN YOUR NOTEBOOK** Students’ summaries should include a description of the four different samples of bacteria Griffith injected into the mice, the fate of the mice injected with each strain, and the conclusion Griffith drew based on his results.

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**How Science Works**

**EARLY INVESTIGATION OF NUCLEIC ACIDS**

Well before the work of Frederick Griffith, experiments had provided information about nucleic acids. In the late 1860s, Friedrich Miescher, a medical researcher, isolated a substance called nuclein while working with white blood cells. Miescher was able to determine that this substance, found in the nuclei of cells, was a complex of protein and an additional compound, which today is known to be nucleic acid, or DNA. He was also able to discover the chemical makeup of nuclein—hydrogen, oxygen, nitrogen, and phosphorus. These results were published in 1871.
Lead a Discussion

Review with students the experimental design used by Avery and his team. Have students identify the manipulated, or independent, variable in the experiment. (the type of enzyme used to treat the extract from heat-killed bacteria) Make sure they realize that only one enzyme was used in each experiment. Then, have them identify the responding, or dependent, variable in this experiment. (whether transformation occurred) Have students state the conclusion that was reached using the results of these experiments. (DNA stores and transmits genetic information.)

DIFFERENTIATED INSTRUCTION

Struggling Students Provide students with a visual representation of Avery’s experiment. Start by drawing a cluster of heat-killed bacteria on the board. Then, draw an arrow from the bacteria to a test tube with liquid in it, while explaining that Avery extracted cellular materials from the bacteria. Draw protein-destroying enzymes being added to this test tube. Then, draw another arrow to a cluster of live R-strain bacteria, and tell students that Avery mixed the enzyme-treated material with the live R-strain bacteria. Finally, show another arrow pointing to live S-strain bacteria. Explain that transformation occurred. Repeat this drawing process to show the effects of an RNA-destroying enzyme. Finally, draw the process for a DNA-destroying enzyme. For this one, talk about why transformation did not occur and how Avery used this result to reach his conclusion that DNA is the transforming factor.

English Language Learners Introduce students to the term bacteriophage. Tell students that the word part -phage is based on the Greek word phagein, meaning “to eat.” Explain that when -phage is added to a noun, it signifies “one who eats.” Have students apply this knowledge to bacteriophage and discuss its meaning. (Students should conclude that bacteriophages “eat,” or destroy, the bacteria they infect.)

Check for Understanding

HAND SIGNALS

Ask students the following questions, and have them show a thumbs-up sign if they can answer a question, a thumbs-down sign if they cannot, or a waving-hand sign if they are unsure.

- What is bacterial transformation?
- What conclusion did Frederick Griffith draw from his experimental results?
- What conclusion did Oswald Avery draw from his experimental results?

If students are confused, have pairs work together to write a one-sentence response to each question.
The Hershey-Chase Experiment

Hershey and Chase studied a bacteriophage that was composed of a DNA core and a protein coat. They wanted to determine which part of the virus—the protein coat or the DNA core—entered the bacterial cell. Their results would either support or disprove Avery’s finding that genes were made of DNA.

The pair grew viruses in cultures containing radioactive isotopes of phosphorus-32 (32P) and sulfur-35 (35S). This was a clever strategy, because proteins contain almost no phosphorus, and DNA contains no sulfur. Therefore, these radioactive substances could be used as markers, enabling the scientists to tell which molecules actually entered the bacteria, carrying the genetic information of the virus. If they found radioactivity from 35S in the bacteria, it would mean that the virus’s protein coat had been injected into the bacteria. If they found 32P, then the DNA core had been injected.

The two scientists mixed the marked viruses with bacterial cells. 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. Figure 12–3 shows the steps in this experiment. What were the results? Nearly all the radioactivity in the bacteria was from phosphorus (32P), the marker found in DNA. Hershey and Chase concluded that the genetic material of the bacteriophage was indeed DNA, not protein.

Hershey and Chase’s experiment with bacteriophages confirmed Avery’s results, convincing many scientists that DNA was the genetic material found in genes—not just in viruses and bacteria, but in all living cells.

In Your Notebook

Identify the independent and dependent variables in the Hershey-Chase experiment, and list some possible control variables.

How Science Works

RADIOISOTOPES—A TOOL FOR BIOLOGISTS

Radioisotopes, or radioactive isotopes, are commonly used by biologists to study cell processes because they can be substituted into biochemical reactions without changing the chemistry of the reactions. Isotopes of an element contain the same number of protons but different numbers of neutrons in their nuclei. Radioisotopes are isotopes that have an unstable nucleus. For example, 32P is an isotope of phosphorus. 32P is not stable, so it “decays” into a more stable form. This decay is detected as radioactivity. Scientists studying a particular biochemical reaction that involves phosphorus can use 32P to monitor the reaction. Radioisotopes of many other elements also exist, giving biologists a wide range of these “tools” to work with.

Answers

IN YOUR NOTEBOOK The independent variable is the substance that was labeled, DNA or protein. The dependent variable is the presence of radioactivity in the infected cell. An example of a control variable is the amount of time Hershey and Chase waited for the viruses to infect the bacteria.
Teach continued

VISUAL ANALOGY
Have students examine Figure 12–4, which uses the analogy of a book to describe the functions of DNA.

Ask Look at the title of the book. In what ways is DNA like a how-to book? (It stores instructions.)

Ask How does DNA store information? (Sample answer: in its molecular structure)

Ask Why is it important that DNA can be accurately copied? (so that each daughter cell receives a complete and correct copy of the genetic material during cell division)

DIFFERENTIATED INSTRUCTION

L1 Special Needs Make a bulleted list on the board of the three main functions of DNA presented in this lesson (storing information, copying information, and transmitting information). Have students use this list to remind them of DNA’s basic functions as they learn more about DNA’s structure and replication in this chapter.

Address Misconceptions

Genes Although most students are familiar with the word gene, many cannot describe the chemical basis of inheritance. As students are introduced to the function of DNA in this lesson, remind them that genes, which are made of DNA, carry a chemical code for biological processes. It is this chemical code that stores genetic information, is copied when a cell divides, and transmits information from one generation to the next.

VISUAL ANALOGY

THE MAIN FUNCTIONS OF DNA

FIGURE 12–4 Like DNA, the book in this diagram contains coded instructions for a cell to carry out important biological processes, such as how to move or transport ions. The book, like DNA, can also be copied and passed along to the next generation. These three tasks—storing, copying, and transmitting information—are also the three main functions of DNA.

The Role of DNA

What is the role of DNA in heredity?

You might think that scientists would have been satisfied knowing that genes were made of DNA, but that was not the case at all. Instead, they wondered how DNA, or any molecule for that matter, could do the critical things that genes were known to do. The next era of study began with one crucial assumption. The DNA that makes up genes must be capable of storing, copying, and transmitting the genetic information in a cell. These three functions are analogous to the way in which you might share a treasured book, as pictured in Figure 12–4.

Storing Information The foremost job of DNA, as the molecule of heredity, is to store information. The genes that make a flower purple must somehow carry the information needed to produce purple pigment. Genes for blood type and eye color must have the information needed for their jobs as well, and other genes have to do even more. Genes control patterns of development, which means that the instructions that cause a single cell to develop into an oak tree, a sea urchin, or a dog must somehow be written into the DNA of each of these organisms.

Copying Information Before a cell divides, it must make a complete copy of one of its genes. To many scientists, the most puzzling aspect of DNA was how it could be copied. The solution to this and other puzzles had to wait until the structure of the DNA molecule became known. Within a few weeks of this discovery, a copying mechanism for the genetic material was put forward. You will learn about this mechanism later in the chapter.

Check for Understanding

ONE-MINUTE RESPONSE

Write the following prompt on the board, and give students about a minute to write a response summarizing their understanding.

What are the three functions of DNA, and why is each function important to living things? (Responses should identify storing, copying, and transmitting information, and they should include an explanation of the importance of each function.)

ADJUST INSTRUCTION

If responses show that students do not understand the three functions of DNA, divide the class into three groups. Assign one function to each group. Then, have each group develop and give a short, creative presentation, such as a rap or song, to help others remember the function.
Copying Information
Before a cell divides, its genetic information must be copied.

Transmitting Information
When a cell divides, each daughter cell must receive a complete copy of the genetic information.

Transmitting Information
As Mendel’s work had shown, genes are transmitted from one generation to the next. Therefore, DNA molecules must be carefully sorted and passed along during cell division. Such careful sorting is especially important during the formation of reproductive cells in meiosis. Remember, the chromosomes of eukaryotic cells contain genes made of DNA. The loss of any DNA during meiosis might mean a loss of valuable genetic information from one generation to the next.

Review Key Concepts
1. a. Review List the conclusions that Griffith and Avery drew from their experiments.
   b. Identify Variables What was the experimental variable that Avery used when he repeated Griffith’s work?
2. a. Review What conclusion did Hershey and Chase draw from their experiments?
   b. Infer 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?
3. a. Review What are the three key roles of DNA?
   b. Apply Concepts Why would the storage of genetic information in genes help explain why chromosomes are separated so carefully during mitosis?

Apply the Big Idea
Science as a Way of Knowing
4. Choose either Griffith, Avery, or Hershey and Chase, and develop a flowchart that shows how that scientist or team of scientists used various scientific methods. Be sure to identify each method. You may use your flowchart from Taking Notes as a guide. If you need to, refer to the descriptions of scientific methods in Chapter 1.

Assessment Answers
1a. Griffith concluded that a heritable substance transforms harmless bacteria into harmful bacteria. Avery found that this heritable substance is DNA.
1b. The experimental variable in Avery’s experiment was the type of molecule-destroying enzyme he used.
2a. Hershey and Chase concluded that DNA is the genetic material found in genes.
2b. Growing viruses in separate cultures that contained both radioactive sulfur and radioactive phosphorus ensured that one sample of the virus had radioactive protein and the other sample had radioactive DNA. If only one type of molecule had been marked, they would not have been able to detect both types of molecule, and the results would not have been conclusive.
3a. storing, copying, and transmitting genetic information
3b. During mitosis, the cell’s DNA is replicated, and each daughter cell receives a copy. If the chromosomes do not separate correctly, the information they carry in DNA might not be passed correctly to the daughter cells.
4. Students’ flowcharts should describe the work of Griffith, Avery, or Hershey and Chase, including their procedures and conclusions.
The Structure of 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 (ád uh neen), guanine (gwah neen), cytosine (say tuh zeen), and thymine (thuh 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.

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Solving 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.

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.

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?
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?

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**Answers**

1. yeast
2. 35% thymine and 15% each of guanine and cytosine
3. It suggested that A is paired with T and G with C in some way.

**FIGURE 12–5** The nucleotides in a strand of DNA are joined by covalent bonds formed between their sugar and phosphate groups.
LESSON 12.2

Focus on ELL:

Have students examine Figure 12–6, and then divide the class into three groups. Assign one of the following scientists or teams to each group: Chargaff, Franklin, and Watson and Crick. Have each group prepare a short presentation describing the contributions of its assigned scientist(s). Ask each group to share its presentation with the class.

DIFFERENTIATED INSTRUCTION

**L3 Advanced Learners** As students are preparing the presentations described above, have advanced learners do additional research to prepare a short report about the Nobel Prize that was awarded to Watson, Crick, and Wilkins for their work on DNA’s structure. Have them learn more about why Maurice Wilkins was included in the prize but Rosalind Franklin was not. Have students share this information when the group reports are presented.

**ELL Focus on ELL:**
**Access Content**

ALL SPEAKERS Have students fold a sheet of paper into thirds to organize the information about Chargaff, Franklin, and Watson and Crick. At the top of each section, have students record the name of the scientist or scientist team. Then, suggest beginning and intermediate speakers make bulleted lists of words or phrases that will help them recall the contributions of each scientist or team. Encourage advanced students to record the information in complete sentences. Require advanced high students to write full, complex sentences that accurately summarize the scientists’ work.

**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.

**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.

**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.”

**Check for Understanding**

**FOLLOW-UP PROBES**

**Ask** How is solving the puzzle of DNA’s structure an example of a collection of discoveries by different scientists? (Although Watson and Crick are remembered as the team that solved the structure of DNA, their work would not have been possible without the work of many other scientists, including those described in this lesson.)

**ADJUST INSTRUCTION**

Use the following demonstration to help students understand the key roles played by scientists other than Watson and Crick to determine DNA’s structure. Open a box containing the pieces of a jigsaw puzzle. Hand one piece of the puzzle to each of four or five students. Point out that the puzzle could not be completed without the pieces held by those students. In the same way, the puzzle of DNA’s structure was solved because many individuals supplied a “piece of the puzzle.”
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.

Quick Facts

THE STRUCTURE OF DNA

When Watson and Crick were ready to announce their double-helix model in 1953, they made a drawing of DNA and sent it with a letter to Nature, a highly respected scientific journal. Nature routinely publishes “letters,” which are much shorter than typical scientific papers. The second and third paragraphs of Watson and Crick’s letter explained why they believed a triple-helix model of DNA, which was being developed by Linus Pauling and other researchers, was incorrect. The letter then proceeded to describe the double-helix model of DNA. They ended the letter 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, Nature published Watson and Crick’s description of the copying mechanism. Their classic paper, titled “A Structure for Deoxyribose Nucleic Acid,” appeared in the April 25, 1953 issue of the journal.

Use Models

Show the class a physical model of a DNA molecule. Point out to students that a double helix looks like a twisted ladder.

Ask If a twisted ladder is used as a model of DNA, which parts of a DNA molecule correspond to the sides of the ladder? (the phosphate group and the 5-carbon sugar deoxyribose)

Ask Which parts of a DNA molecule correspond to the rungs of the ladder? (nitrogenous base pairs)

DIFFERENTIATED INSTRUCTION

Special Needs Draw a picture of a ladder on the board. Explain how the ladder can model the structure of DNA. Label the rungs of the ladder Nitrogenous Bases and the sides of the ladder Sugar and Phosphate Groups. Ask students to imagine what the ladder would look like if it were twisted. Then, show them a physical model of DNA. Help them make the connection between the ladder drawing and the DNA model by pointing out the nitrogenous bases, phosphate groups, and sugar molecules.

Students should infer that exposure to UV light may interfere with proper base pairing in the DNA of skin cells. Students can go online to Biology.com to gather their evidence.

Answers

IN YOUR NOTEBOOK Students’ models should depict DNA as a double helix, with labels identifying the nitrogenous bases, deoxyribose, and phosphate groups.
Assess and Remediate

**LESSON 12.2**

**EVALUATE UNDERSTANDING**

Read the first Key Question for this lesson to the class. Then, ask a volunteer to provide an answer. Continue until each of the three Key Questions has been answered. Then, have students complete the 12.2 Assessment.

**REMEDICATION SUGGESTION**

**1 Struggling Students** If students have difficulty answering Question 1b, remind them that hydrogen bonds are a type of weak chemical bond.

---

**12.2 Assessment**

**Review Key Concepts**

1. **Review** List the chemical components of DNA.
2. **Relate Cause and Effect** Why are hydrogen bonds so essential to the structure of DNA?
   **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.

---

**Assessment Answers**

1a. 5-carbon sugar molecules, phosphate groups, four different nitrogenous bases

1b. Hydrogen bonds hold the paired nitrogenous bases together. Because hydrogen bonds are weak bonds, the two strands of DNA are easily separated—a characteristic that is important to DNA's function.

2a. Chargaff determined that, in a double-stranded DNA molecule, adenine and thymine are present in equal proportions and guanine and cytosine are present in equal proportions. Franklin's X-ray photographs of DNA revealed a spiral structure. Both of these findings helped Watson and Crick understand DNA's double helix and complementary base pairing.

2b. DNA is too small to be examined with a light microscope—the only kind of microscope available at the time.

3a. Watson and Crick's model is composed of two antiparallel strands that are connected by hydrogen bonds between nitrogenous bases. Hydrogen bonds form between adenine and thymine and between cytosine and guanine.

3b. Watson and Crick's model depicted DNA as a double helix with adenine and thymine paired together. This pairing accounts for the equal amounts of thymine and adenine in DNA.

**Visual Thinking**

4. Students’ models should show the structure of DNA as a double helix and include correct base pairing between adenine and thymine and between cytosine and guanine.
Discovering the Role of DNA  Genes and the principles of genetics 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.

1865  Gregor Mendel shows that the characteristics of pea plants are passed along in a predictable way. His discovery begins the science of genetics.

1903  Walter Sutton shows that chromosomes carry the cell's units of inheritance.

1911  Thomas Hunt Morgan demonstrates that genes are arranged in linear fashion on the chromosomes of the fruit fly.

1928  Frederick Griffith discovers that bacteria contain a molecule that can transfer genetic information from cell to cell.

1944  Oswald Avery, Colin MacLeod, and Maclyn McCarty show the substance that Griffith discovered is DNA.

1950  Erwin Chargaff analyzes the base composition of DNA in cells. He discovers that the amounts of adenine and thymine are almost always equal, as are the amounts of guanine and cytosine.

1952  Alfred Hershey and Martha Chase confirm that the genetic material of viruses is DNA, not protein.

1953  James Watson and Francis Crick publish their model of the DNA double helix. The model was made possible by Franklin's work.

2000  Craig Venter and Francis Collins announce the draft DNA sequence of the human genome at a White House ceremony in Washington, D.C. The final version is published in 2003.


differentiated instruction

Struggling Students  Have students take turns reading aloud the time line entries, moving in chronological order. After each entry has been read, have a brief discussion of the significance of the discovery.

Advanced Students  Explain that the most recent entry on the time line, the sequencing of the human genome, is a project that built on all of the previous discoveries in the time line. Have students imagine a future entry for the time line, based on what they know about genetics and what they envision as future applications of genetics. Have each student share his or her imagined time line entry with the class.

How Science Works

SCIENTISTS ARE A SKEPTICAL BUNCH

Today, it seems clear that Avery’s results had shown 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 whether bacteria had genes like those in more complex organisms. And even if DNA were the heredity 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 satisfied with 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.

Teach

Lead a Discussion

Have students examine the time line to learn more about the history of genetics research. Ask them questions to make sure they understand the information presented on the page.

Ask How many years passed between the work of Mendel and the announcement of the draft of the human genome? (135 years)

Ask What did Walter Sutton find? (Walter Sutton found that the chromosomes carry genes.)

Ask How does Rosalind Franklin’s work illustrate the connection between technology and science? (Rosalind Franklin’s work would not have been possible without X-ray diffraction technology.)

Answers

WRITING

Students’ responses will vary based on their research. Students might note that both Watson and Crick went on to research how DNA controls protein synthesis.

NATIONAL SCIENCE EDUCATION STANDARDS

UCP II, V

CONTENT C.2.a, G.1, G.3

INQUIRY A.2.a
Getting Started

Objectives
12.3.1 Summarize the events of DNA replication.
12.3.2 Compare DNA replication in prokaryotes with that of eukaryotes.

Student Resources
Study Workbooks A and B, 12.3 Worksheets
Spanish Study Workbook, 12.3 Worksheets
Lab Manual B, 12.2 Hands-On Activity

Build Background
Have students suggest ways to make a copy of a page of the text. (Sample answers: by hand, by using a copier) Ask them why it is important to make an exact copy. (so the information doesn’t change) Explain that cells copy DNA in a process called DNA replication.

Answers
IN YOUR NOTEBOOK Sample answer: DNA separates into two strands and produces two new complementary strands by the rules of base pairing.

NATIONAL SCIENCE EDUCATION STANDARDS
UNIFYING CONCEPTS AND PROCESSES
I, V

CONTENT
C.2.a, C.2.c

INQUIRY
A.1.b, A.1.d

DNA Replication

THINK ABOUT IT Before a cell divides, its DNA must first be copied. How might the double-helix structure of DNA make that possible? What might happen if one of the nucleotides were damaged or chemically altered just before the copying process? How might this affect the DNA inherited by each daughter cell after cell division?

Copying the Code
What role does DNA polymerase play in copying DNA?
When Watson and Crick discovered the structure of DNA, they immediately recognized one genuinely surprising aspect of the structure. Base pairing in the double helix explains how DNA can be copied, or replicated, because each base on one strand pairs with one—and only one—base on the opposite strand. Each strand of the double helix therefore has all the information needed to reconstruct the other half by the mechanism of base pairing. Because each strand can be used to make the other strand, the strands are said to be complementary.

The Replication Process
Before a cell divides, it duplicates its DNA in a copying process called replication. This process, which occurs during late interphase of the cell cycle, ensures that each resulting cell has the same complete set of DNA molecules. During replication, the DNA molecule separates into two strands and then produces two new complementary strands following the rules of base pairing. Each strand of the double helix of DNA serves as a template, or model, for the new strand.

Figure 12–8 shows the process of DNA replication. The two strands of the double helix have separated, or “unzipped,” allowing two replication forks to form. As each new strand forms, new bases are added following the rules of base pairing. If the base on the old strand is adenine, then thymine is added to the newly forming strand. Likewise, guanine is always paired to cytosine. For example, a strand that has the base sequence TAGGCT produces a strand with the complementary base sequence ATGCAA. The result is two DNA molecules identical to each other and to the original molecule. Note that each DNA molecule resulting from replication has one original strand and one new strand.

In Your Notebook In your own words, describe the process of DNA replication.

Teach for Understanding
ENDURING UNDERSTANDING DNA is the universal code for life; it enables an organism to transmit hereditary information and, along with the environment, determines an organism’s characteristics.

GUIDING QUESTION How do cells copy their DNA?

EVIDENCE OF UNDERSTANDING After completing the lesson, give students the following assessment to show they understand how cells copy their DNA. Have students work in small groups to make a series of three diagrams. The first diagram should show a labeled 15-base section of double-stranded DNA. The second diagram should show what the DNA would look like during the replication process. The third diagram should show the results of replication. Remind students to label each nitrogenous base and to follow the rules of base pairing.
The Role of Enzymes  DNA replication is carried out by a series of enzymes. These enzymes first "unzip" a molecule of DNA by breaking the hydrogen bonds between base pairs and unwinding the two strands of the molecule. Each strand then serves as a template for the attachment of complementary bases. You may recall that enzymes are proteins with highly specific functions. For this reason, they are often named for the reactions they catalyze. The principal enzyme involved in DNA replication is called DNA polymerase (pahl ih mur ayz). DNA polymerase is an enzyme that joins individual nucleotides to produce a new strand of DNA. Besides producing the sugar-phosphate bonds that join nucleotides together, DNA polymerase also "proofreads" each new DNA strand, so that each molecule is a near-perfect copy of the original.

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During DNA replication, the DNA molecule produces two new complementary strands. Each strand of the double helix serves as a template for the new strand. The micrograph shows a pair of replication forks in human DNA. Apply Concepts What makes the new DNA strand complementary to the original strand?

How Science Works

THE DISCOVERY OF DNA POLYMERASE

In 1959, Arthur Kornberg, a researcher in the field of enzymology, won a Nobel Prize for the discovery of DNA polymerase. This groundbreaking work was summarized in two scientific papers. The first paper described the extraction and purification of DNA polymerase from bacteria; the second paper described an analysis of the substances required for DNA synthesis, including DNA polymerase. These two papers were submitted to the Journal of Biological Chemistry in 1957. Both papers were initially rejected. After intervention by a newly hired editor-in-chief, the papers were published in 1958.

Teach

Use Visuals

Have students use Figure 12–8 to clarify the process of DNA replication.

Ask How is DNA unzipped at the replication forks? (Hydrogen bonds are broken.)

Ask What are the two roles of DNA polymerase in replication? (DNA polymerase joins individual nucleotides to produce a new strand of DNA and proofreads the new strand.)

DIFFERENTIATED INSTRUCTION

L Struggling Students  Write the following sentence starters on the board.

- During replication, DNA polymerase . . .
- At the replication fork, . . .
- During replication, each original DNA strand . . .

Ask students to write a phrase to complete each sentence. Then, ask volunteers to share their responses with the class.

L Advanced Students  Explain to advanced students that enzymes are critical to the process of DNA replication, just as they are to most chemical reactions in living things. Have students find the name of, and learn more about, the enzyme that unwinds and unzips DNA during replication (helicase). Ask them to share their findings with the class.

Have students discuss what might happen if a UV-induced base change was copied during the process of DNA replication. Students can go online to Biology.com to gather their evidence.

Students can watch an animated version of DNA replication by accessing InterActive Art: DNA Replication.

Answers

FIGURE 12–8  The new DNA strand is complementary to the original strand because its base sequence is determined by the rules of base pairing.
Lesson 12.3

**Teach continued**

**Build Reading Skills**

Point out the head Replication in Living Cells. Have students use this head to start an outline of the material in this section. Show them how to incorporate the two subheads for prokaryotic and eukaryotic DNA replication. After students have completed their outlines, ask volunteers to share them with the class.

**DIFFERENTIATED INSTRUCTION**

**ELL Less Proficient Readers** Encourage struggling readers to work in small groups to prepare the outline of the information in this section, as described above. Students can divide the reading among members of the group and share what they learn to create the outline.

**Build Background**

**ALL SPEAKERS** Divide students into four groups of mixed speaking levels. Then, have them complete a Gallery Walk activity. Ask the groups to rotate between four locations in the classroom where you have posted questions about lesson content, such as “What happens during DNA replication?” or “What does DNA polymerase do?” At each location, have an intermediate or advanced speaker read the question aloud. Then, ask beginning speakers to give a short oral response to the question. Have advanced high speakers prepare a written response in the form of at least one complete, complex sentence. Groups should also read, evaluate, and comment on any of the previous groups’ answers.

**Study Wkbks A/B, Appendix S6, Gallery Walk.**

**Focus on ELL: Build Background**

**ELL**

**Focus on ELL: Build Background**

**LESSON 12.3**

**LESSON 12.3**

**DIFFERENTIATED INSTRUCTION**

**ELL Less Proficient Readers** Encourage struggling readers to work in small groups to prepare the outline of the information in this section, as described above. Students can divide the reading among members of the group and share what they learn to create the outline.

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**Study Wkbks A/B, Appendix S6, Gallery Walk.**

**Modeling DNA Replication**

1. Cut out small squares of white and yellow paper to represent phosphate and sugar molecules. Then, cut out small strips of blue, green, red, and orange paper to represent the four nitrogenous bases. Build a set of five nucleotides using your paper strips and tape. Look back at Figure 12–5 if you need help.

2. Using your nucleotides, tape together a single strand of DNA. Exchange strands with a partner.

**Replication in Living Cells**

**Telomeres** DNA at the tips of chromosomes are known as telomeres (Figure 12–9). This DNA is particularly difficult to replicate. Cells use a special enzyme, called telomerase, to solve this problem by adding short, repeated DNA sequences to the telomeres. In rapidly dividing cells, such as stem cells and embryonic cells, telomerase helps to prevent genes from being damaged or lost during replication. Telomerase is often switched off in adult cells. In cancer cells, however, telomerase may be activated, enabling these cells to grow and proliferate rapidly.

**Quick Lab**

**PURPOSE** Students will model DNA replication.

**MATERIALS** colored paper, tape, scissors

**PLANNING** Have students review the structure of DNA before completing the Quick Lab. Suggest students tape together the individual nucleotides before taping the strand together.

**ANALYZE AND CONCLUDE**

1. DNA polymerase

2. Sample answer: This lab models how the bases in a sequence of DNA are paired with complementary bases. To better show the steps of replication, I would make lots more nucleotides and join two long strands of bases together to indicate that a DNA molecule is double-stranded. I would then be able to model how the two strands separate and how complementary bases are added, resulting in two new complementary strands.
**Prokaryotic DNA Replication**

In most prokaryotes, DNA replication does not start until regulatory proteins bind to a single starting point on the chromosome. These proteins then trigger the beginning of the S phase, and DNA replication begins. **Replication in most prokaryotic cells starts from a single point and proceeds in two directions until the entire chromosome is copied.** This process is shown in Figure 12–10. Often, the two chromosomes produced by replication are attached to different points inside the cell membrane and are separated when the cell splits to form two new cells.

**Eukaryotic DNA Replication**

Eukaryotic chromosomes are generally much bigger than those of prokaryotes. **In eukaryotic cells, replication may begin at dozens or even hundreds of places on the DNA molecule, proceeding in both directions until each chromosome is completely copied.** Although a number of proteins check DNA for chemical damage or base pair mismatches prior to replication, the system is not foolproof. Damaged regions of DNA are sometimes replicated, resulting in changes to DNA base sequences that may alter certain genes and produce serious consequences.

The two copies of DNA produced by replication in each chromosome remain closely associated until the cell enters prophase of mitosis. At that point, the chromosomes condense, and the two chromatids in each chromosome become clearly visible. They separate from each other in anaphase of mitosis, as described in Chapter 10, producing two cells, each with a complete set of genes coded in DNA.

**FIGURE 12–10 Differences in DNA Replication**

Replication in most prokaryotic cells (top) begins at a single starting point and proceeds in two directions until the entire chromosome is copied. In eukaryotic cells (bottom), replication proceeds from multiple starting points on individual chromosomes and ends when all the chromosomes are copied.

**Assessment Answers**

1a. The DNA molecule separates into two strands at the replication fork. Each individual strand is then used as a template for the attachment of complementary bases.

1b. DNA polymerase joins individual nucleotides to produce a new strand of DNA and proofreads each new strand.

2a. DNA in prokaryotic cells is found in the form of a single circular chromosome in the cytoplasm; DNA in eukaryotic cells is found in the nucleus, packaged into bigger, individual chromosomes.

2b. If damaged DNA is replicated, the cell that receives it may have altered genes, which could lead to serious consequences.

3. Students’ Venn diagrams should include for prokaryotic replication only: occurs in the cytoplasm, DNA arranged in a single circular chromosome, starts at just one point and continues around the circle until it is completed; for eukaryotic replication only: occurs in the nucleus, begins at several points on the DNA molecule; for both: DNA polymerase joins nucleotides, new DNA strands are complementary to the strands they were made from.
**Pre-Lab**

Introduce students to the concepts they will explore in the chapter lab by assigning the Pre-Lab questions.

**Lab**

Tell students they will perform the chapter lab *Extracting DNA* described in Lab Manual A.

**Struggling Students** A simpler version of the chapter lab is provided in Lab Manual B.

**SAFETY**

Students should wear safety goggles while performing this lab. Have students wash their hands when they complete the lab. Students should use caution with glassware and follow the lab instructions exactly.

**PRE-LAB QUESTIONS**

**1. Apply Concepts** Why do strawberry cells need DNA?

**2. Form a Hypothesis** If you observe a cell nucleus under a compound microscope, you will not see a molecule of DNA. Why will you be able to see the DNA you extract?

**3. Predict** Use what you know about DNA to predict some of the physical properties of DNA.

**4. Design an Experiment** How could you determine what percentage of a strawberry's mass is DNA?

**PRE-LAB QUESTIONS**

1. Sample answer: Strawberry cells need DNA to produce the proteins that control reactions within its cells.

2. The clump of DNA will contain DNA from many cells.

3. Sample answer: The solid DNA will be made up of thin long threads. The solid will be flexible rather than rigid.

4. Measure the mass of the strawberry and the mass of the extracted DNA. Divide the mass of the DNA by the mass of the strawberry.
12.3 DNA Replication

DNA polymerase is an enzyme that joins individual nucleotides to produce a new strand of DNA.

Replication in most prokaryotic cells starts from a single point and proceeds in two directions until the entire chromosome is copied.

In eukaryotic cells, replication may begin at dozens or even hundreds of places on the DNA molecule, proceeding in both directions until each chromosome is completely copied.

Think Visually
Using the information in this chapter, complete the following concept map about DNA replication:

DNA Replication

1. In Prokaryotes
   - starts at
   - and proceeds

2. In Eukaryotes
   - starts at
   - and proceeds

3. The sites where replication occurs are called telomeres.

4. The sites where replication occurs are called replication forks.

Performance Tasks

SUMMATIVE TASK Tell students to imagine they have been hired as tutors to teach this chapter to a group of students. Have them work in small groups to create a slide presentation that could be used to teach chapter content. Each presentation should consist of at least ten slides of text and graphics. Tell students their presentation must convey information about each lesson Key Question. Have groups share their presentations with the class.

TRANSFER TASK Have students imagine they are either James Watson or Francis Crick. The year is 1953, and Watson and Crick have just submitted their paper describing DNA's structure to the journal *Nature*. In their role as Watson or Crick, have students write a letter to a friend explaining the model of DNA. The letter should also describe the work of at least three other scientists whose work influenced the development of the model.

Answers

THINK VISUALLY
1. a single point
2. dozens or even hundreds of places
3. in both directions
4. in both directions
5. replication forks
Lesson 12.1

Understand Key Concepts

1. b  2. d  3. c  4. b

5. A chemical factor can be transferred from dead bacteria to living bacteria that can change the heritable characteristics of the living bacteria.

6. DNA contains phosphorus, but protein does not. Protein contains sulfur, but DNA does not. This allowed radioactive phosphorus and radioactive sulfur to identify each molecule specifically.

Think Critically

7. Griffith heated a culture of a disease-causing strain of bacteria, which killed the bacteria but did not destroy the DNA. When he mixed the heat-killed, disease-causing bacteria with live, harmless bacteria, the DNA from the disease-causing bacteria was transferred to the live bacteria. These bacteria and their offspring caused pneumonia in the mice.

8. Avery and his team used enzymes to destroy various biological molecules. They showed that when DNA was destroyed, genetic information could not be transferred. Destroying other biological molecules did not have the same effect.

Lesson 12.2

Understand Key Concepts

9. b  10. a  11. c

12. A nucleotide has three parts: a 5-carbon sugar called deoxyribose, a phosphate group, and a nitrogenous base.

13. Chargaff’s rules of base pairing gave Watson and Crick confidence that their model was correct, because their model agreed with Chargaff’s observations of the relative percentages of A, T, G, and C in DNA.

14. The scattering pattern of X-rays sent through a sample of DNA showed that the molecule was helical and consisted of two strands.

15. The two strands of DNA are antiparallel, which means that the bases can line up in the two strands and form hydrogen bonds between the A–T and G–C pairs.

Think Critically

7. Interpret Visuals Look back at Griffith’s experiment shown in Figure 12–1. Describe the occasion in which the bacterial DNA withstood conditions that killed the bacteria. What happened to the DNA during the rest of the experiment?

8. Evaluate Avery and his team identified DNA as the molecule responsible for the transformation seen in Griffith’s experiment. How did they control variables in their experiment to make sure that only DNA caused the effect?

Lesson 12.3

Understand Key Concepts

18. c  19. a  20. a  21. d

22. Base pairing is the principle that hydrogen bonds form only between certain base pairs: adenine and thymine, cytosine and guanine. In replication, base pairing ensures that the new complementary strands are identical to the original strands.

23. In a typical prokaryotic cell, DNA is found in the cytoplasm in a single circular chromosome.

24. DNA separates into two strands, then two new complementary strands are generated following the rules of base pairing. Each new DNA molecule has one strand from the original molecule and one newly synthesized strand, making each new DNA molecule an exact duplicate of the original.
18. In prokaryotes, DNA molecules are located in the
   a. nucleus. c. cytoplasm.  
   b. ribosomes. d. histones.  

19. In eukaryotes, nearly all the DNA is found in the
   a. nucleus. c. cytoplasm.  
   b. ribosomes. d. histones.  

20. The diagram below shows the process of DNA
   a. replication. c. transformation.  
   b. digestion. d. transpiration.  

21. The main enzyme involved in linking individual nucleotides into DNA molecules is
   a. DNA protease. c. carbohydrase.  
   b. ribose. d. DNA polymerase.  

22. What is meant by the term base pairing? How is base pairing involved in DNA replication?  

23. Describe the appearance of DNA in a typical prokaryotic cell.  

24. Explain the process of replication. When a DNA molecule is replicated, how do the new molecules compare to the original molecule?  

Think Critically
25. Use Analogies Is photocopying a document similar to DNA replication? Think of the original materials, the copying process, and the final products. Explain how the two processes are alike. Identify major differences.  

26. Compare and Contrast Describe the similarities and differences between DNA replication in prokaryotic cells and in eukaryotic cells.  

THINK CRITICALLY
25. Photocopying a document is similar in some ways to DNA replication. In both processes, you start with one copy and end up with two identical copies. However, the copying process is different. In photocopying, the original is copied, so you end up with one original copy and one completely new copy. In DNA replication, the original molecule splits in half, so you end up with two copies that are half original and half new.  

26. Similarities: DNA replication in both eukaryotes and prokaryotes proceeds in both directions and results in two identical strands of DNA. Differences: prokaryotic DNA replication occurs in the cytoplasm and begins at a single point on the chromosome; eukaryotic DNA replication occurs in the nucleus and begins in many places on a chromosome.  

UV LIGHT
The nucleotides in DNA include the nitrogenous bases adenine, cytosine, guanine, and thymine (A, C, G, and T). The energy from UV light can produce chemical changes in these bases, damaging the DNA molecule and producing errors when DNA is replicated.

1. Predict Use your understanding of the structure of DNA to predict what sorts of problems excessive UV light might produce in the DNA molecule. How might these changes affect the functions of DNA?  

2. Infer All cells have systems of enzymes that repair UV-induced damage to their DNA. Some cellular systems block DNA replication if there are base pairing problems in the double helix. Why are these systems important? How might they work?  

3. Relate Cause and Effect Analyze the effects that UV light might have on skin cells. Why is UV light so dangerous? Why is the skin particularly vulnerable to it?  

4. Connect to the Big Idea Among humans who inherit genetic defects in their DNA-repair systems, the incidence of skin cancer is as much as 1000 times greater than average. Based on this information, what can you infer about the effect of UV light on DNA?  

After students have read through the Chapter Mystery, have a discussion about the connection between UV light and changes in DNA.

Ask What part of the DNA molecule is changed by exposure to UV light? (the nitrogenous bases)  

Explain that UV light damages DNA by inducing changes in its structure, which consequently affect function. For example, UV light induces the formation of pyrimidine dimers (covalent linking between adjacent pyrimidine bases), which block normal DNA replication.

Ask How might exposure to UV light change DNA’s ability to store, copy, or transmit information? (Any change in the structure of DNA could lead to changes in stored information and could interfere with the accurate copying of the information. This might lead to incorrect information being transmitted to daughter cells during cell division.)  

Ask How could this information be used to inform others of the importance of wearing sunscreen? (Describing how UV light damages DNA would allow you to use scientific information to support your argument that wearing sunscreen is a healthful action.)

CHAPTER MYSTERY ANSWERS
1. Sample answer: The energy from UV light can cause chemical changes in the bases. It might cause the formation of new bonds or the breaking of old ones, preventing the DNA molecule from replicating properly.  

2. Sample answer: They are important because they prevent damaged DNA from passing along incorrect information when it replicates. They might work by disabling DNA polymerase.  

3. UV light is dangerous because it can cause chemical changes in DNA. The skin is particularly vulnerable because it covers and protects most of the body and is the organ that is subject to the greatest exposure to UV light.  

4. Sample answer: The fact that people with genetic defects in their DNA repair systems have a higher incidence of skin cancer, and the fact that excessive exposure to UV light causes skin cancer, provides evidence that for the effect of UV light on DNA—UV light damages DNA, and DNA damage is associated with cancer.  

Have students watch the short video DNA Super Sleuth to see how scientists use DNA to solve crimes.
Connecting Concepts

USE SCIENCE GRAPHICS

27. about 260 nm

28. Ultraviolet light, particularly between 250 and 270 nm wavelengths, is harmful to living organisms.

29. Sample answer: As more ozone is destroyed, does the amount of UV radiation that reaches Earth’s surface increase?

WRITE ABOUT SCIENCE

30. Answers will vary. In their letters to Mendel, students should describe the structure of a typical eukaryotic gene, the structure of DNA, and how genes are parts of chromosomes.

31. Sample answer: Two strands with paired bases held together by weak hydrogen bonds can be easily pulled apart. New bases lined up on the two strands by base-pairing rules would generate two molecules with the same base sequence.

Use Science Graphics

A scientist studied the effect of exposing DNA to various wavelengths of ultraviolet light. The scientist determined the number of copying errors made after exposure to ultraviolet rays. The graph shows the results. Use the graph to answer questions 27 and 28.

27. Interpret Graphs. The most damaging effects of ultraviolet light on DNA replication occur at which wavelength?

28. Infer. What conclusion would you draw from the graph about the effect of ultraviolet light on living organisms?

29. Pose Questions. Ozone is a molecule that is very effective at absorbing ultraviolet light from the sun. Evidence indicates that human activities have contributed to the destruction of ozone in the atmosphere. What question would you ask about the effect of removing ozone from the atmosphere?

Write About Science

30. Explanation. Recall that Gregor Mendel concluded that factors, which we now call genes, determine the traits that pass from one generation to the next. Imagine that you could send a letter backward in time to Mendel. Write a letter to him in which you explain what a gene consists of in molecular terms.

31. Assess the Big Idea. In their original paper describing the structure of DNA, Watson and Crick noted in a famous sentence that the structure they were proposing immediately suggested how DNA could make a copy of itself. Explain what Watson and Crick meant when they said this.

The following table shows the results of measuring the percentages of the four bases in the DNA of several different organisms. Some of the values are missing from the table.

<table>
<thead>
<tr>
<th>Organism</th>
<th>A</th>
<th>G</th>
<th>T</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>19.9</td>
<td>29.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chicken</td>
<td>28.8</td>
<td></td>
<td>21.5</td>
<td></td>
</tr>
<tr>
<td>Bacterium</td>
<td></td>
<td></td>
<td></td>
<td>13.4</td>
</tr>
</tbody>
</table>

32. Predict. Based on Chargaff’s rule, the percentage of adenine bases in human DNA should be around

a. 30.9%.

b. 19.9%.

c. 21.5%.

d. 13.4%.

33. Calculate. The value for the percent of guanine bases in the bacterium would be expected to be about

a. 13.4%.

b. 28.8%.

c. 36.6%.

d. There is not enough information given.

34. Predict. If the two DNA strands of the bacterium were separated and the base composition of just one of the strands was determined, you could expect

a. the amount of A to equal the amount of T.

b. the amount of C to equal the amount of G.

c. the amount of A to equal the amounts of T, C, and G.

d. the four nitrogenous bases to have any value.

ANSWERS

32. a

33. c

34. d

Purpose. Students will apply Chargaff’s rules to determine the relationship between the percentages of nitrogenous bases in DNA from a few organisms.

Planning. Remind students that, according to base pairing, adenine bonds with thymine and guanine bonds with cytosine.
Multiple Choice

1. During replication, which sequence of nucleotides would bond with the DNA sequence TATGA?
   A. TATGA   C. CACTA
   B. ATACT   D. AGTAT

2. The scientist(s) responsible for the discovery of bacterial transformation is (are)
   A. Watson and Crick.  C. Griffith.
   B. Avery.  D. Franklin.

3. Which of the following does NOT describe the structure of DNA?
   A. double helix
   B. nucleotide polymer
   C. contains adenine-guanine pairs
   D. sugar-phosphate backbone

4. What did Hershey and Chase’s work show?
   A. Genes are probably made of DNA.
   B. Genes are probably made of protein.
   C. Viruses contain DNA but not protein.
   D. Bacteria contain DNA but not protein.

5. The two “backbones” of the DNA molecule consist of
   A. adenines and sugars.
   B. phosphates and sugars.
   C. adenines and thymines.
   D. thymines and sugars.

6. In eukaryotic chromosomes, DNA is tightly coiled around proteins called
   A. DNA polymerase.
   B. chromatin.
   C. histones.
   D. nucleotides.

7. When prokaryotic cells copy their DNA, replication begins at
   A. one point on the DNA molecule.
   B. two points on opposite ends of the DNA molecule.
   C. dozens to hundreds of points along the molecule.
   D. opposite ends of the molecule.

8. Compared to eukaryotic cells, prokaryotic cells contain
   A. about 1000 times more DNA.
   B. about one thousandth as much DNA.
   C. twice as much DNA.
   D. the same amount of DNA.

Questions 9–10

Under ideal conditions, a single bacterial cell can reproduce every 20 minutes. The graph shows how the total number of cells under ideal conditions can change over time.

9. How many cells are present after 80 minutes?
   A. 1  C. 16
   B. 2  D. 32

10. If the DNA of this bacterium is 4 million base pairs in length, how many total molecules of A, T, C, and G are required for replication to be successful?
    A. 2 million
    B. 4 million
    C. 8 million
    D. 32 million

Open-Ended Response

11. Describe how eukaryotic cells are able to keep such large amounts of DNA in the small volume of the cell nucleus.

If You Have Trouble With . . .

<table>
<thead>
<tr>
<th>Question</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
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Test-Taking Tip

USE SCRATCH PAPER

Tell students that when they are asked to find the solution to a problem, such as the complementary sequence of DNA, they should first solve the problem on scratch paper. They should then compare their answer with the options provided. This method will help them avoid answer choices that are very similar, but not identical to, the correct answer choice.