Identifying the Substance of Genes

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

Taking Notes

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.

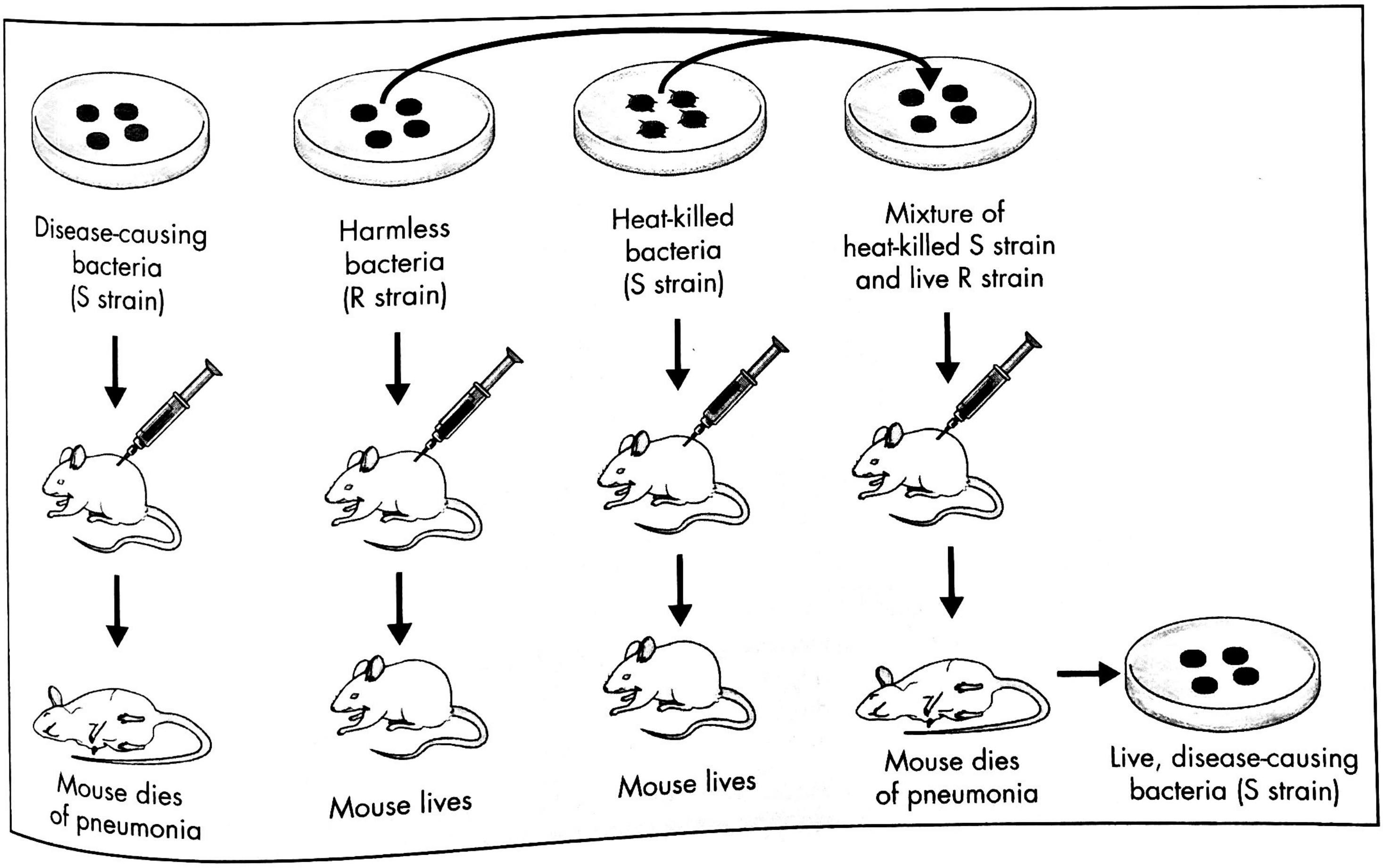
Griffith's Experiments When Griffith injected mice with disease-causing bacteria, the mice developed pneumonia and died. When he injected mice with harmless bacteria, the mice stayed healthy. Griffith wondered what made the first group of mice get pneumonia. Perhaps the S-strain bacteria produced a toxin 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.

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 Somehow, the heat-killed bacteria 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.*

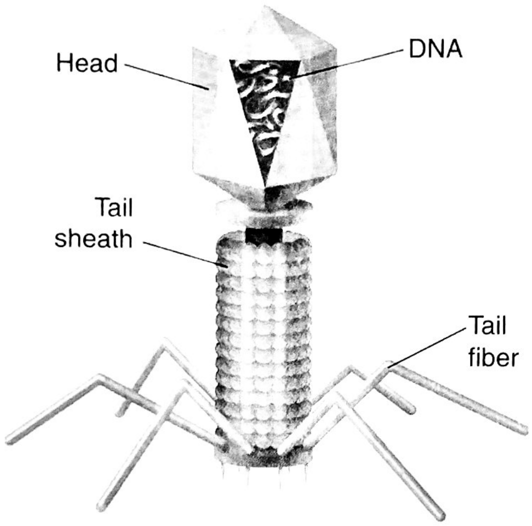
FIGURE 12–1 Griffith's Experiments Griffith injected mice with four different samples of bacteria. When injected separately, neither heat-killed, disease-causing bacteria nor live, harmless bacteria killed the mice. The two strains injected together, however, caused fatal pneumonia. From this experiment, 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?***



The Molecular Cause of Transformation In 1944, a group of scientists at the Rockefeller Institute in New York decided to repeat Griffith's work. Led by the Canadian biologist Oswald Avery, the scientists wanted to determine which molecule in the heat-killed bacteria was most important for transformation. They reasoned that if they could find this particular molecule, it might reveal the chemical nature of the gene.

Avery and his team extracted a mixture of various molecules from the heat-killed bacteria. They carefully treated this mixture with enzymes that destroyed proteins, lipids, carbohydrates, and some other molecules, including the nucleic acid RNA. Transformation still occurred. Clearly, since those molecules had been destroyed, none of them could have been responsible for transformation.

Avery's team repeated the experiment one more time. This time, they used enzymes that would break down a different nucleic acid—DNA. When they destroyed the DNA in the mixture, transformation did not occur. There was just one possible explanation for these results: *DNA was the transforming factor.* **By observing bacterial transformation, Avery and other scientists discovered that the nucleic acid DNA stores and transmits genetic information from one generation of bacteria to the next.**



Bacterial Viruses

What role did bacterial viruses play in identifying genetic material?

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 the experiments relating to the discovery made by Avery's team was performed in 1952 by two American scientists, Alfred Hershey and Martha Chase. They collaborated in studying viruses—tiny, nonliving particles that can infect living cells.

Bacteriophages A **bacteriophage** is a kind of virus that infects bacteria. When a bacteriophage enters a bacterium, it attaches to the surface of the bacterial cell and injects its genetic information into it, as shown in **Figure 12–2.** The viral genes act to produce many new bacteriophages, which gradually destroy the bacterium. When the cell splits open, hundreds of new viruses burst out.

FIGURE 12–2 Bacteriophages A bacteriophage is a type of virus that infects and kills bacteria. The top diagram shows a bacteriophage known as T4. The micrograph shows three T2 bacteriophages (green) invading an *E. coli* bacterium (gold). **Compare and Contrast** *How large are viruses compared with bacteria?*

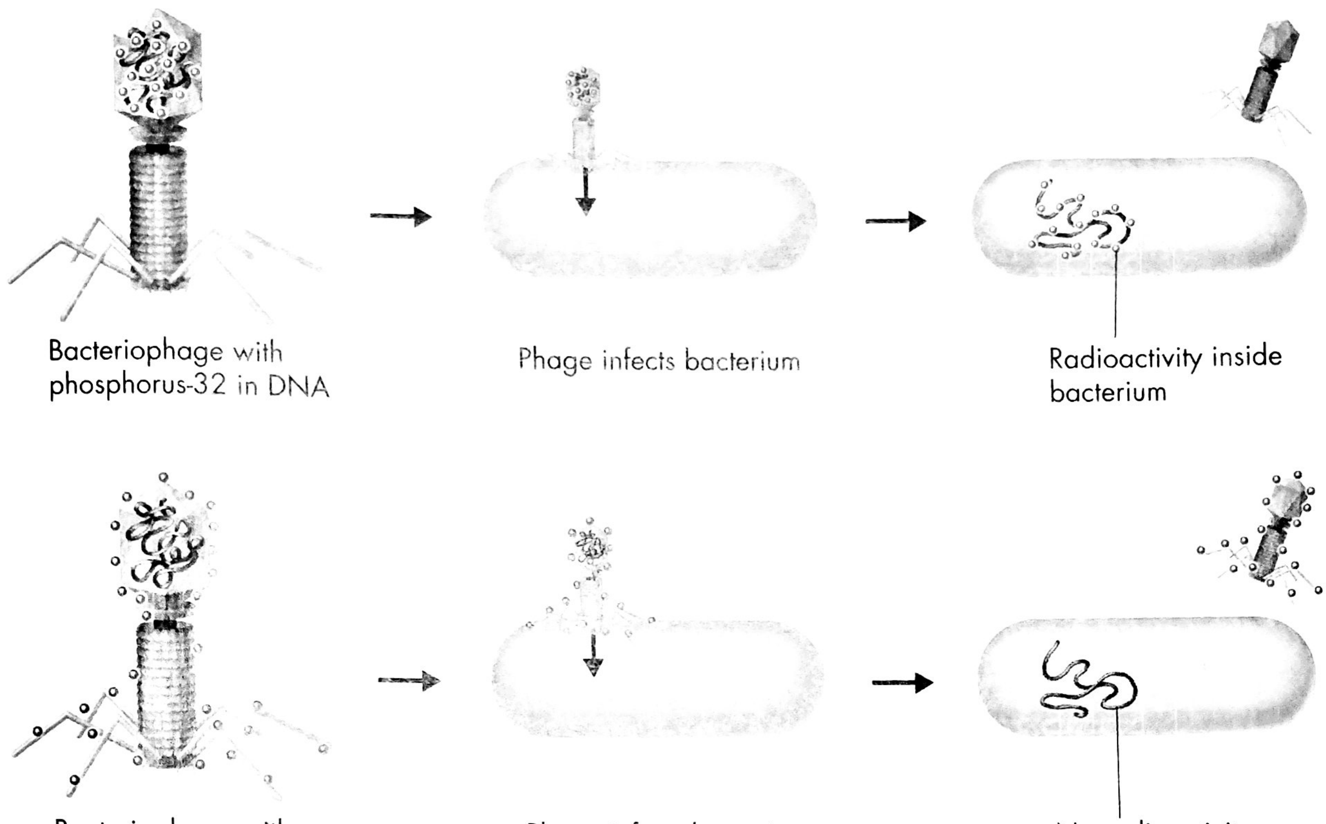


FIGURE 12–3 Hershey-Chase Experiment Alfred Hershey and Martha Chase used different radioactive markers to label the DNA and proteins of bacteriophages. The bacteriophages injected only DNA, not proteins, into bacterial cells.

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.

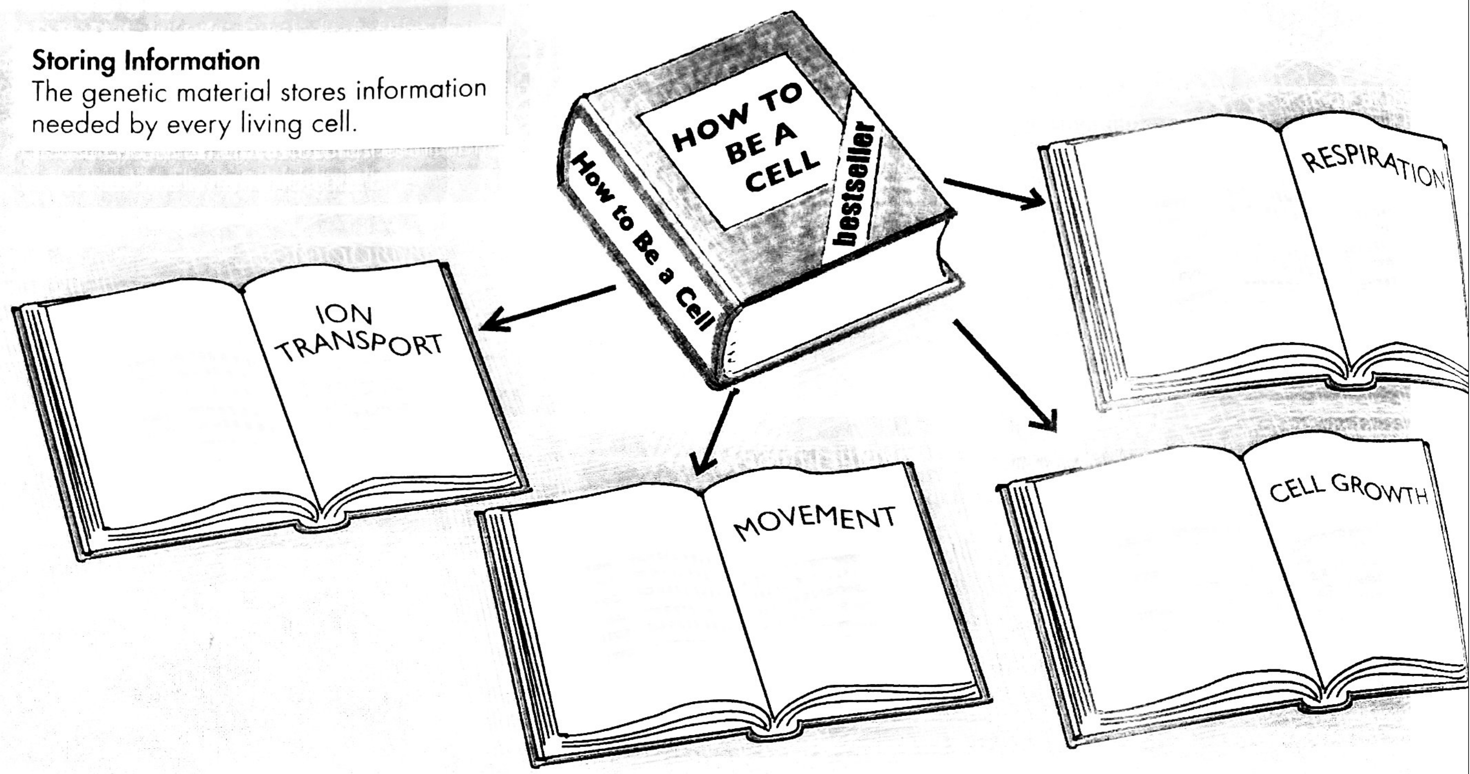
The pair grew viruses in cultures containing radioactive isotopes of phosphorus-32 (^{32}P) and sulfur-35 (^{35}S). This was a clever strategy, because proteins contain almost no phosphorus, and DNA contains no sulfur. Therefore, these radioactive substances could be used as markers, enabling the scientists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

Storing Information

The genetic material stores information needed by every living cell.



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.

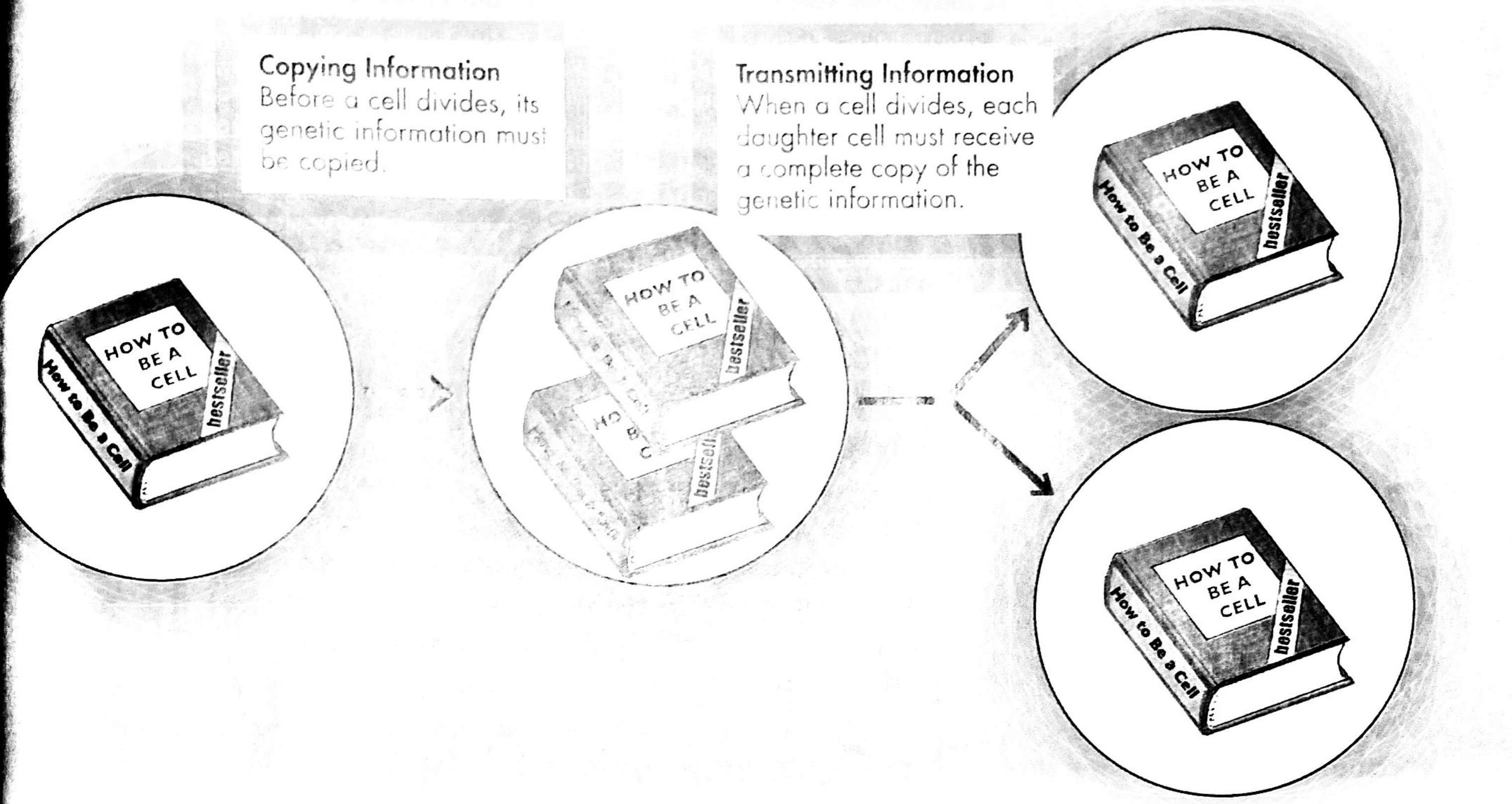
The Role of DNA

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 every 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.



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.

12.1 Assessment

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. **Research to Build and Present Knowledge** Choose Griffith, Avery, or Hershey and Chase. Select evidence from the text to develop a flowchart that shows how that scientist or team of scientists used scientific methods. Be sure to identify each method. Use your flowchart from Taking Notes and content from Chapter 1 as a guide.