SECTION 1

What Does DNA Look Like?

For many years, the structure of a DNA molecule was a puzzle to scientists. In the 1950s, two scientists deduced the structure while experimenting with chemical models. They later won a Nobel Prize for helping solve this puzzle!

What You Will Learn

- List three important events that led to understanding the structure of DNA.
- Describe the basic structure of a DNA molecule.
- Explain how DNA molecules can be copied.

Vocabulary

DNA
nucleotide

READING STRATEGY

Prediction Guide Before reading this section, write the title of each heading in this section. Next, under each heading, write what you think you will learn.

Inherited characteristics are determined by genes, and genes are passed from one generation to the next. Genes are parts of chromosomes, which are structures in the nucleus of most cells. Chromosomes are made of protein and DNA. **DNA** stands for *deoxyribonucleic acid* (dee AHKS ee RIE boh noo KLEE ik AS id). DNA is the genetic material—the material that determines inherited characteristics. But what does DNA look like?

The Pieces of the Puzzle

Scientists knew that the material that makes up genes must be able to do two things. First, it must be able to give instructions for building and maintaining cells. Second, it must be able to be copied each time a cell divides, so that each cell contains identical genes. Scientists thought that these things could be done only by complex molecules, such as proteins. They were surprised to learn how much the DNA molecule could do.

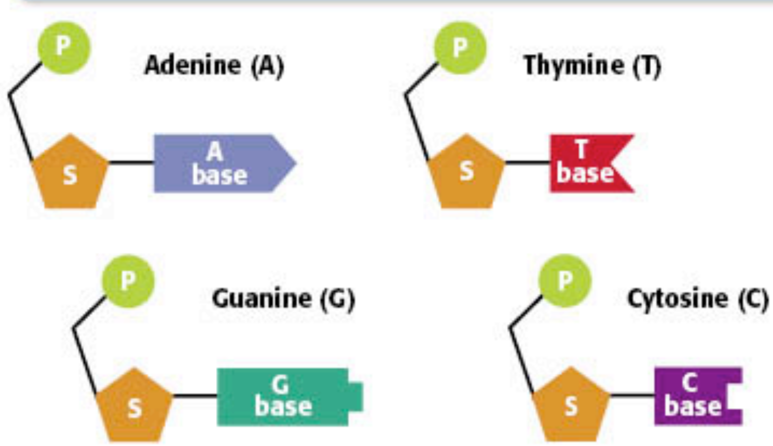
Nucleotides: The Subunits of DNA

DNA is made of subunits called nucleotides. A **nucleotide** consists of a sugar, a phosphate, and a base. The nucleotides are identical except for the base. The four bases are *adenine, thymine, guanine,* and *cytosine*. Each base has a different shape. Scientists often refer to a base by the first letter of the base, *A, T, G,* and *C*. **Figure 1** shows models of the four nucleotides.

DNA deoxyribonucleic acid, a molecule that is present in all living cells and that contains the information that determines the traits that a living thing inherits and needs to live

nucleotide in a nucleic-acid chain, a subunit that consists of a sugar, a phosphate, and a nitrogenous base

Figure 1 The Four Nucleotides of DNA



Chargaff's Rules

In the 1950s, a biochemist named Erwin Chargaff found that the amount of adenine in DNA always equals the amount of thymine. And he found that the amount of guanine always equals the amount of cytosine. His findings are known as *Chargaff's rules*. At the time of his discovery, no one knew the importance of these findings. But Chargaff's rules later helped scientists understand the structure of DNA.

Reading Check **Summarize Chargaff's rules.** *(See the Appendix for answers to Reading Checks.)*

Franklin's Discovery

More clues about the structure of DNA came from scientists in Britain. There, chemist Rosalind Franklin, shown in **Figure 2,** was able to make images of DNA molecules. She used a process known as *X-ray diffraction* to make these images. In this process, X rays are aimed at the DNA molecule. When an X ray hits a part of the molecule, the ray bounces off. The pattern made by the bouncing rays is captured on film. Franklin's images suggested that DNA has a spiral shape.

Watson and Crick's Model

At about the same time, two other scientists were also trying to solve the mystery of DNA's structure. They were James Watson and Francis Crick, shown in **Figure 3.** After seeing Franklin's X-ray images, Watson and Crick concluded that DNA must look like a long, twisted ladder. They were then able to build a model of DNA by using simple materials from their laboratory. Their model perfectly fit with both Chargaff's and Franklin's findings. The model eventually helped explain how DNA is copied and how it functions in the cell.

CONNECTION TO Chemistry

WRITING SKILL **Linus Pauling** Many scientists contributed to the discovery of DNA's structure. In fact, some scientists competed to be the first to make the discovery. One of these competitors was a chemist named Linus Pauling. Research and write a paragraph about how Pauling's work helped Watson and Crick.

Figure 2 *Rosalind Franklin used X-ray diffraction to make images of DNA that helped reveal the structure of DNA.*

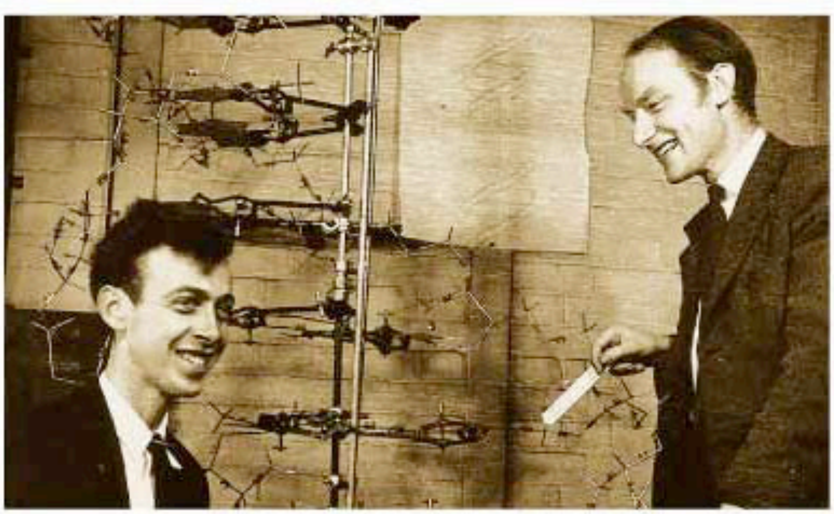


Figure 3 *This photo shows James Watson (left) and Francis Crick (right) with their model of DNA.*

Quick Lab

Making a Model of DNA

1. Gather assorted simple materials that you could use to build a basic model of DNA. You might use **clay, string, toothpicks, paper, tape, plastic foam,** or **pieces of food.**
2. Work with a partner or a small team to build your model. Use your book and other resources to check the details of your model.
3. Show your model to your classmates. Give your classmates feedback about the scientific aspects of their models.

DNA's Double Structure

The shape of DNA is shown in **Figure 4.** As you can see, a strand of DNA looks like a twisted ladder. This shape is known as a *double helix* (DUB uhl HEE LIKS). The two sides of the ladder are made of alternating sugar parts and phosphate parts. The rungs of the ladder are made of a pair of bases. Adenine on one side of a rung always pairs with thymine on the other side. Guanine always pairs with cytosine.

Notice how the double helix structure matches Chargaff's observations. When Chargaff separated the parts of a sample of DNA, he found that the matching bases were always present in equal amounts. To model how the bases pair, Watson and Crick tried to match Chargaff's observations. They also used information from chemists about the size and shape of each of the nucleotides. As it turned out, the width of the DNA ladder matches the combined width of the matching bases. Only the correct pairs of bases fit within the ladder's width.

Making Copies of DNA

The pairing of bases allows the cell to *replicate*, or make copies of, DNA. Each base always bonds with only one other base. Thus, pairs of bases are *complementary* to each other, and both sides of a DNA molecule are complementary. For example, the sequence CGAC will bond to the sequence GCTG.

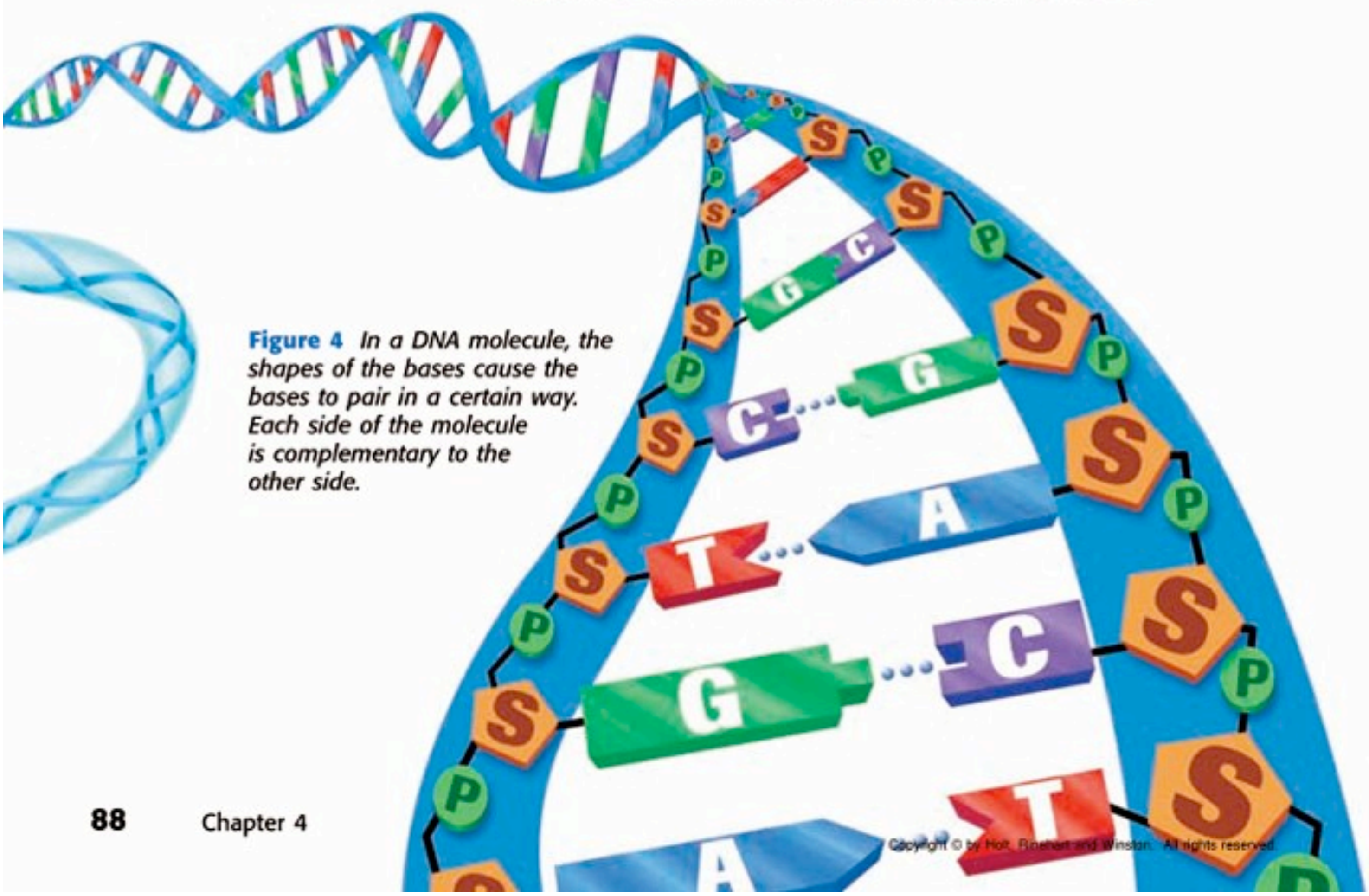


Figure 4 *In a DNA molecule, the shapes of the bases cause the bases to pair in a certain way. Each side of the molecule is complementary to the other side.*

How Copies Are Made

During replication, as shown in **Figure 5,** a DNA molecule is split down the middle, where the bases meet. The bases on each side of the molecule are used as a pattern for a new strand. As the bases on the original molecule are exposed, complementary nucleotides are added to each side of the ladder. Two DNA molecules are formed. Half of each of the molecules is old DNA, and half is new DNA.

When Copies Are Made

DNA is copied every time a cell divides. Each new cell gets a complete copy of all the DNA. The job of unwinding, copying, and re-winding the DNA is done by proteins within the cell. So, DNA is usually found with several kinds of proteins. Other proteins help with the process of carrying out the instructions written in the code of the DNA.

✓ Reading Check How often is DNA copied?

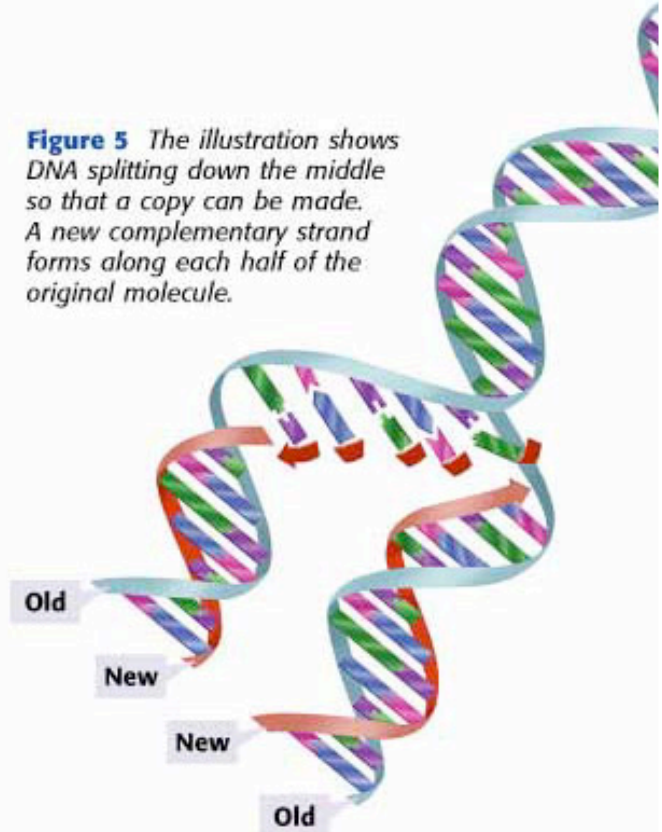


Figure 5 *The illustration shows DNA splitting down the middle so that a copy can be made. A new complementary strand forms along each half of the original molecule.*

SECTION Review

Summary

- DNA is the material that makes up genes. It carries coded information that is copied in each new cell.
- The DNA molecule looks like a twisted ladder. The two halves are long strings of nucleotides. The rungs are complementary pairs of bases.
- Because each base has a complementary base, DNA can be replicated accurately.

Using Key Terms

1. Use the term *DNA* in a sentence.
2. In your own words, write a definition for the term *nucleotide*.

Understanding Key Ideas

3. List three important events that led to understanding the structure of DNA.
4. Which of the following is NOT part of a nucleotide?
   a. base
   b. sugar
   c. fat
   d. phosphate

Math Skills

5. If a sample of DNA contained 20% cytosine, what percentage of guanine would be in this sample? What percentage of adenine would be in the sample? Explain.

Critical Thinking

6. **Making Inferences** Explain what is meant by the statement "DNA unites all organisms."
7. **Applying Concepts** What would the complementary strand of DNA be for the sequence of bases below?

   C T T A G G C T T A C C A

8. **Analyzing Processes** How are copies of DNA made? Draw a picture as part of your answer.

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For a variety of links related to this chapter, go to www.scilinks.org

Topic: DNA; Genes and Traits
SciLinks code: HSM0418; HSM0647

SECTION 2

How DNA Works

Almost every cell in your body contains about 2 m of DNA. How does all of the DNA fit in a cell? And how does the DNA hold a code that affects your traits?

What You Will Learn

- Explain the relationship between DNA, genes, and proteins.
- Outline the basic steps in making a protein.
- Describe three types of mutations, and provide an example of a gene mutation.
- Describe two examples of uses of genetic knowledge.

Vocabulary

RNA
ribosome
mutation

READING STRATEGY

Reading Organizer As you read this section, make a flowchart of the steps of how DNA codes for proteins.

DNA is found in the cells of all organisms, including bacteria, mosquitoes, and humans. Each organism has a unique set of DNA. But DNA functions the same way in all organisms.

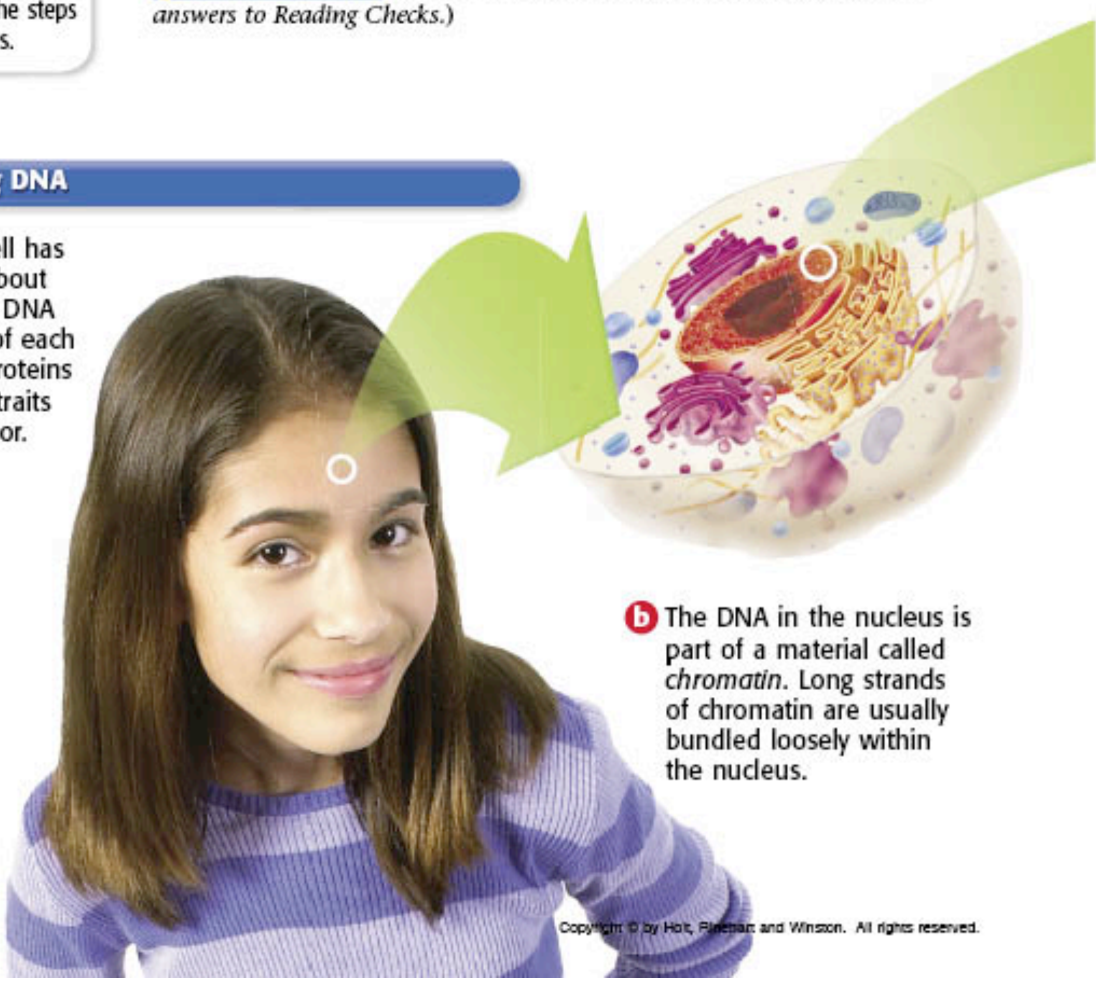
Unraveling DNA

DNA is often wound around proteins, coiled into strands, and then bundled up even more. In a cell that lacks a nucleus, each strand of DNA forms a loose loop within the cell. In a cell that has a nucleus, the strands of DNA and proteins are bundled into chromosomes, as shown in **Figure 1.**

The structure of DNA allows DNA to hold information. The order of the bases on one side of the molecule is a code that carries information. A *gene* consists of a string of nucleotides that give the cell information about how to make a specific trait. There is an enormous amount of DNA, so there can be a large variety of genes.

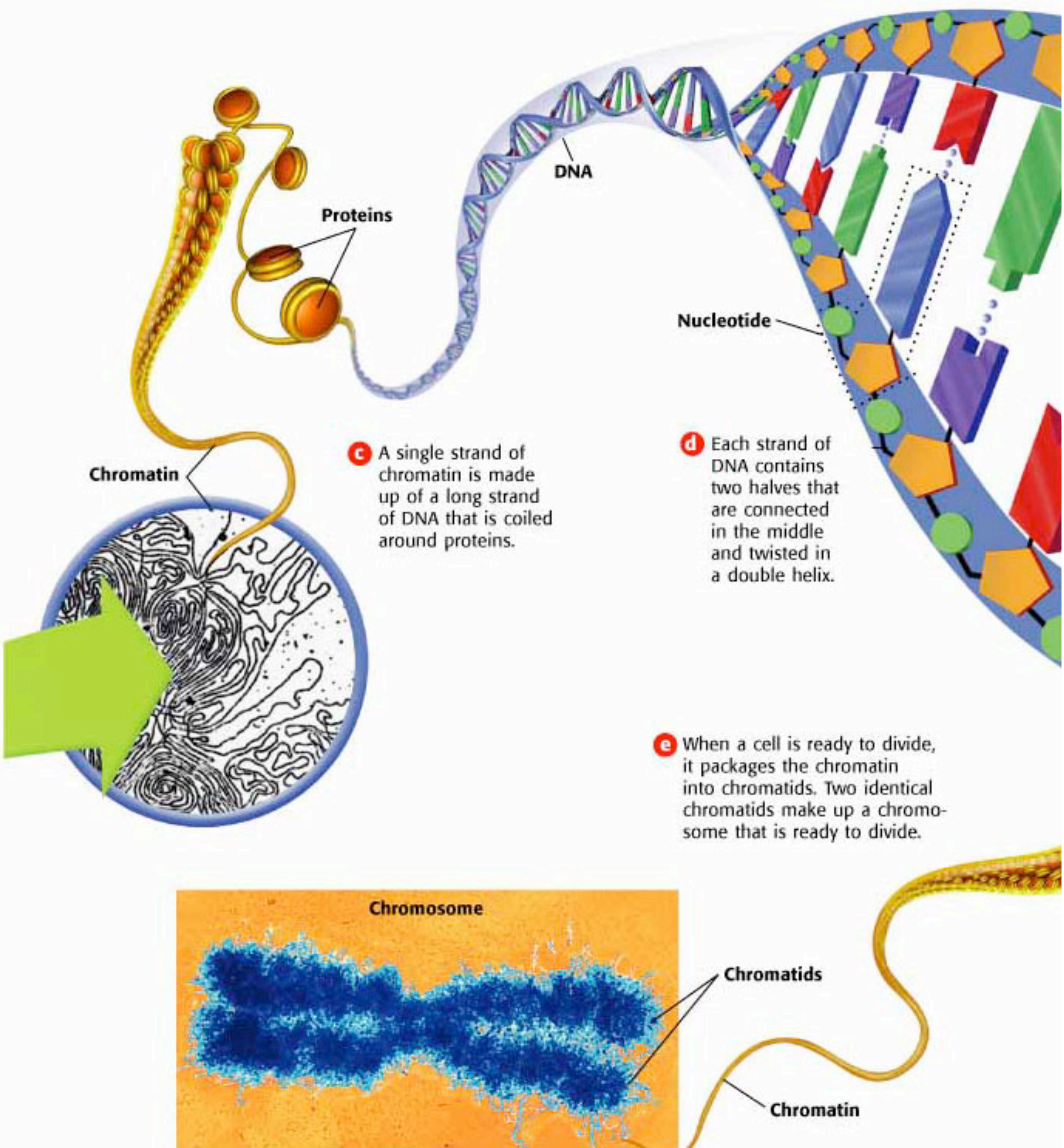
Reading Check **What makes up a gene?** (*See the Appendix for answers to Reading Checks.*)

Figure 1 **Unraveling DNA**



a A typical skin cell has a diameter of about 0.0025 cm. The DNA in the nucleus of each cell codes for proteins that determine traits such as skin color.

b The DNA in the nucleus is part of a material called *chromatin*. Long strands of chromatin are usually bundled loosely within the nucleus.



c A single strand of chromatin is made up of a long strand of DNA that is coiled around proteins.

d Each strand of DNA contains two halves that are connected in the middle and twisted in a double helix.

e When a cell is ready to divide, it packages the chromatin into chromatids. Two identical chromatids make up a chromosome that is ready to divide.

f Just before division, each human cell contains 46 chromosomes. These chromosomes contain two identical copies of all of the cell's genetic material.

Genes and Proteins

The DNA code is read like a book—from one end to the other and in one direction. The bases form the alphabet of the code. Groups of three bases are the codes for specific amino acids. For example, the three bases CCA form the code for the amino acid proline. The bases AGC form the code for the amino acid serine. A long string of amino acids forms a protein. Thus, each gene is usually a set of instructions for making a protein.

INTERNET ACTIVITY

For another activity related to this chapter, go to **go.hrw.com** and type in the keyword **HL5DNAW.**

Proteins and Traits

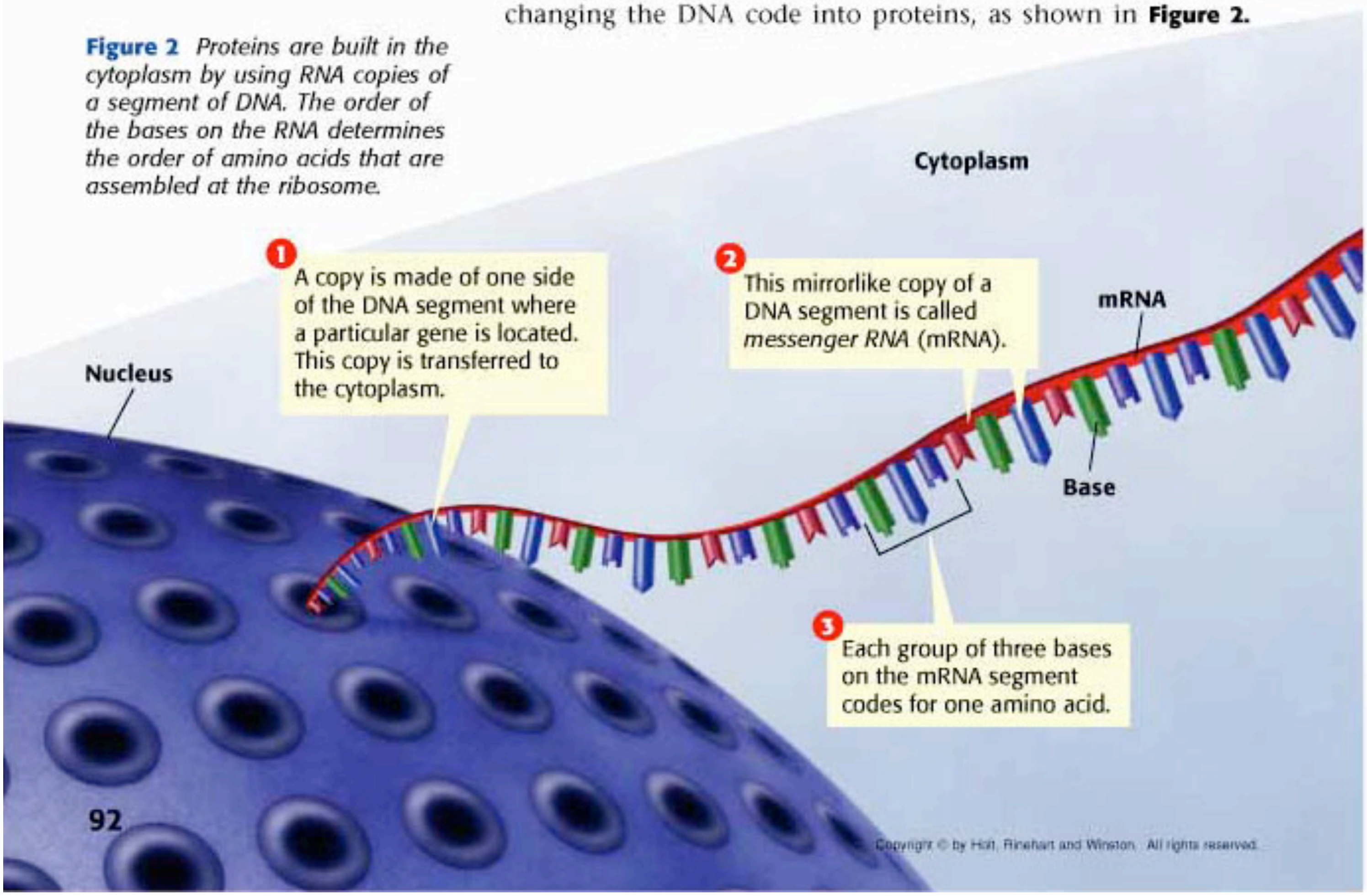
How are proteins related to traits? Proteins are found throughout cells and cause most of the differences that you can see among organisms. Proteins act as chemical triggers and messengers for many of the processes within cells. Proteins help determine how tall you grow, what colors you can see, and whether your hair is curly or straight. Proteins exist in an almost limitless variety. A single organism may have thousands of genes that code for thousands of proteins.

RNA ribonucleic acid, a molecule that is present in all living cells and that plays a role in protein production

Help from RNA

Another type of molecule that helps make proteins is called **RNA,** or *ribonucleic acid* (RIE boh noo KLEE ik AS id). RNA is so similar to DNA that RNA can serve as a temporary copy of a DNA sequence. Several forms of RNA help in the process of changing the DNA code into proteins, as shown in **Figure 2.**

Figure 2 *Proteins are built in the cytoplasm by using RNA copies of a segment of DNA. The order of the bases on the RNA determines the order of amino acids that are assembled at the ribosome.*



The Making of a Protein

The first step in making a protein is to copy one side of the segment of DNA containing a gene. A mirrorlike copy of the DNA segment is made out of RNA. This copy of the DNA segment is called *messenger RNA* (mRNA). It moves out of the nucleus and into the cytoplasm of the cell.

In the cytoplasm, the messenger RNA is fed through a protein assembly line. The "factory" that runs this assembly line is known as a ribosome. A **ribosome** is a cell organelle composed of RNA and protein. The messenger RNA is fed through the ribosome three bases at a time. Then, molecules of *transfer RNA* (tRNA) translate the RNA message. Each transfer RNA molecule picks up a specific amino acid from the cytoplasm. Inside the ribosome, bases on the transfer RNA match up with bases on the messenger RNA like pieces of a puzzle. The transfer RNA molecules then release their amino acids. The amino acids become linked in a growing chain. As the entire segment of messenger RNA passes through the ribosome, the growing chain of amino acids folds up into a new protein molecule.

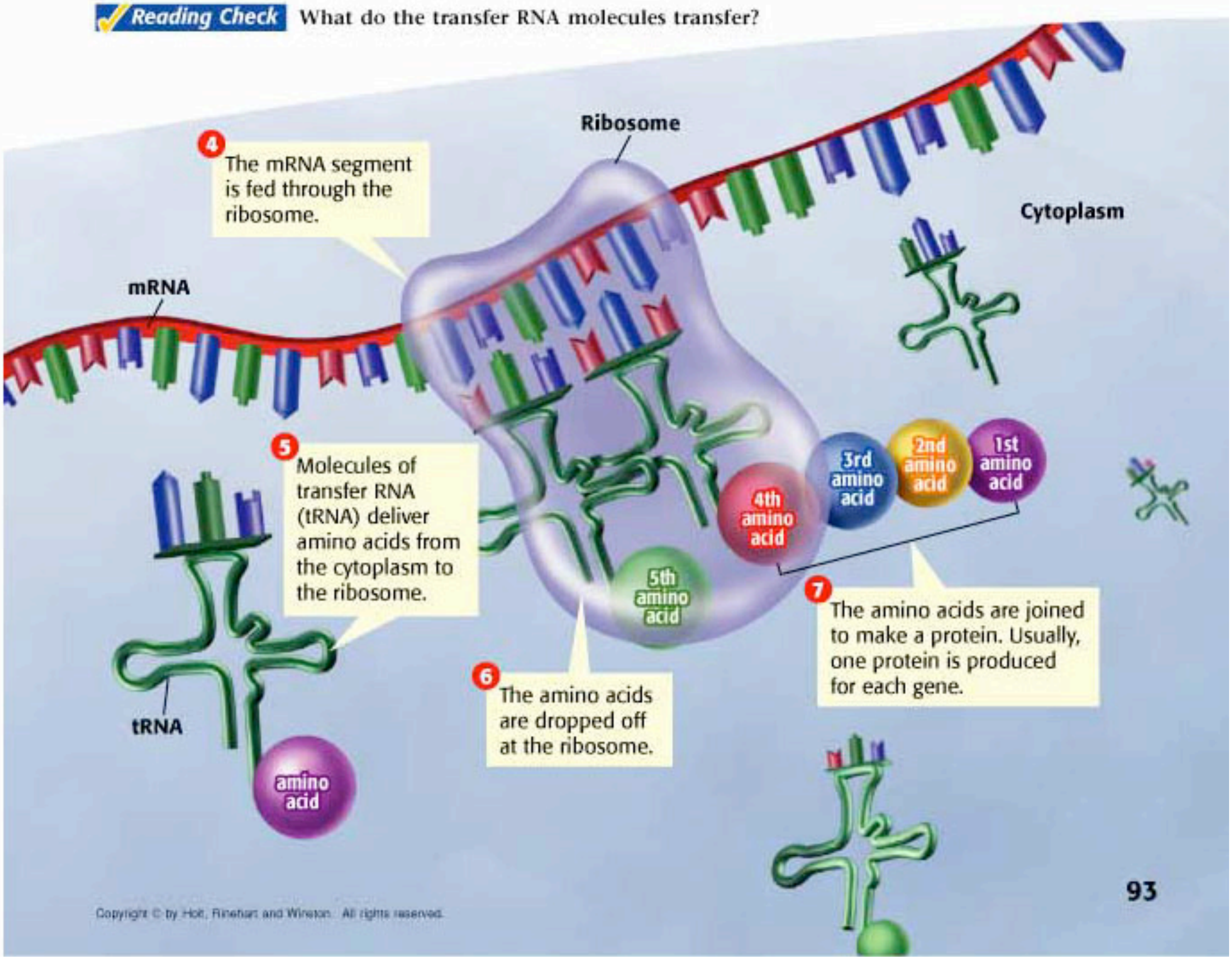
Reading Check **What do the transfer RNA molecules transfer?**

MATH PRACTICE

Code Combinations

A given sequence of three bases codes for one amino acid. For example, AGT is one possible sequence. How many different sequences of the four DNA base types are possible? (Hint: Make a list.)

ribosome a cell organelle composed of RNA and protein; the site of protein synthesis



Changes in Genes

Imagine that you have been invited to ride on a new roller coaster at the state fair. Before you climb into the front car, you are told that some of the metal parts on the coaster have been replaced by parts made of a different substance. Would you still want to ride this roller coaster? Perhaps a strong metal was used as a substitute. Or perhaps a material that is not strong enough was used. Imagine what would happen if cardboard were used instead of metal!

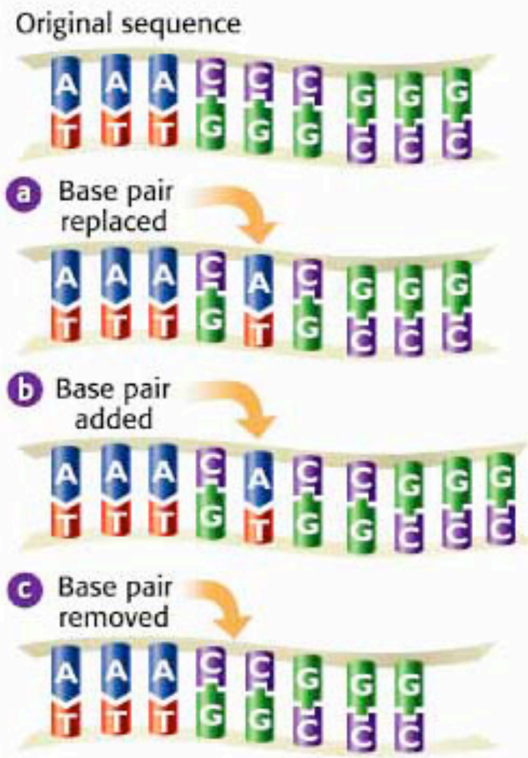


Figure 3 *The original base sequence on the top has been changed to illustrate (a) a substitution, (b) an insertion, and (c) a deletion.*

Mutations

Substitutions like the ones in the roller coaster can accidentally happen in DNA. Changes in the number, type, or order of bases on a piece of DNA are known as **mutations.** Sometimes, a base is left out. This kind of change is known as a *deletion*. Or an extra base might be added. This kind of change is known as an *insertion*. The most common change happens when the wrong base is used. This kind of change is known as a *substitution*. **Figure 3** illustrates these three types of mutations.

Do Mutations Matter?

There are three possible consequences to changes in DNA: an improved trait, no change, or a harmful trait. Fortunately, cells make some proteins that can detect errors in DNA. When an error is found, it is usually fixed. But occasionally the repairs are not accurate, and the mistakes become part of the genetic message. If the mutation occurs in the sex cells, the changed gene can be passed from one generation to the next.

mutation a change in the nucleotide-base sequence of a gene or DNA molecule

How Do Mutations Happen?

Mutations happen regularly because of random errors when DNA is copied. In addition, damage to DNA can be caused by abnormal things that happen to cells. Any physical or chemical agent that can cause a mutation in DNA is called a *mutagen*. Examples of mutagens include high-energy radiation from X rays and ultraviolet radiation. Ultraviolet radiation is one type of energy in sunlight. It is responsible for suntans and sunburns. Other mutagens include asbestos and the chemicals in cigarette smoke.

Reading Check **What is a mutagen?**

An Example of a Substitution

A mutation, such as a substitution, can be harmful because it may cause a gene to produce the wrong protein. Consider the DNA sequence GAA. When copied as mRNA, this sequence gives the instructions to place the amino acid glutamic acid into the growing protein. If a mistake happens and the original DNA sequence is changed to GTA, the sequence will code for the amino acid valine instead.

This simple change in an amino acid can cause the disease *sickle cell disease*. Sickle cell disease affects red blood cells. When valine is substituted for glutamic acid in a blood protein, as shown in **Figure 4,** the red blood cells are changed into a sickle shape.

The sickle cells are not as good at carrying oxygen as normal red blood cells are. Sickle cells are also likely to get stuck in blood vessels and cause painful and dangerous clots.

Reading Check **What causes sickle cell disease?**

SCHOOL to HOME

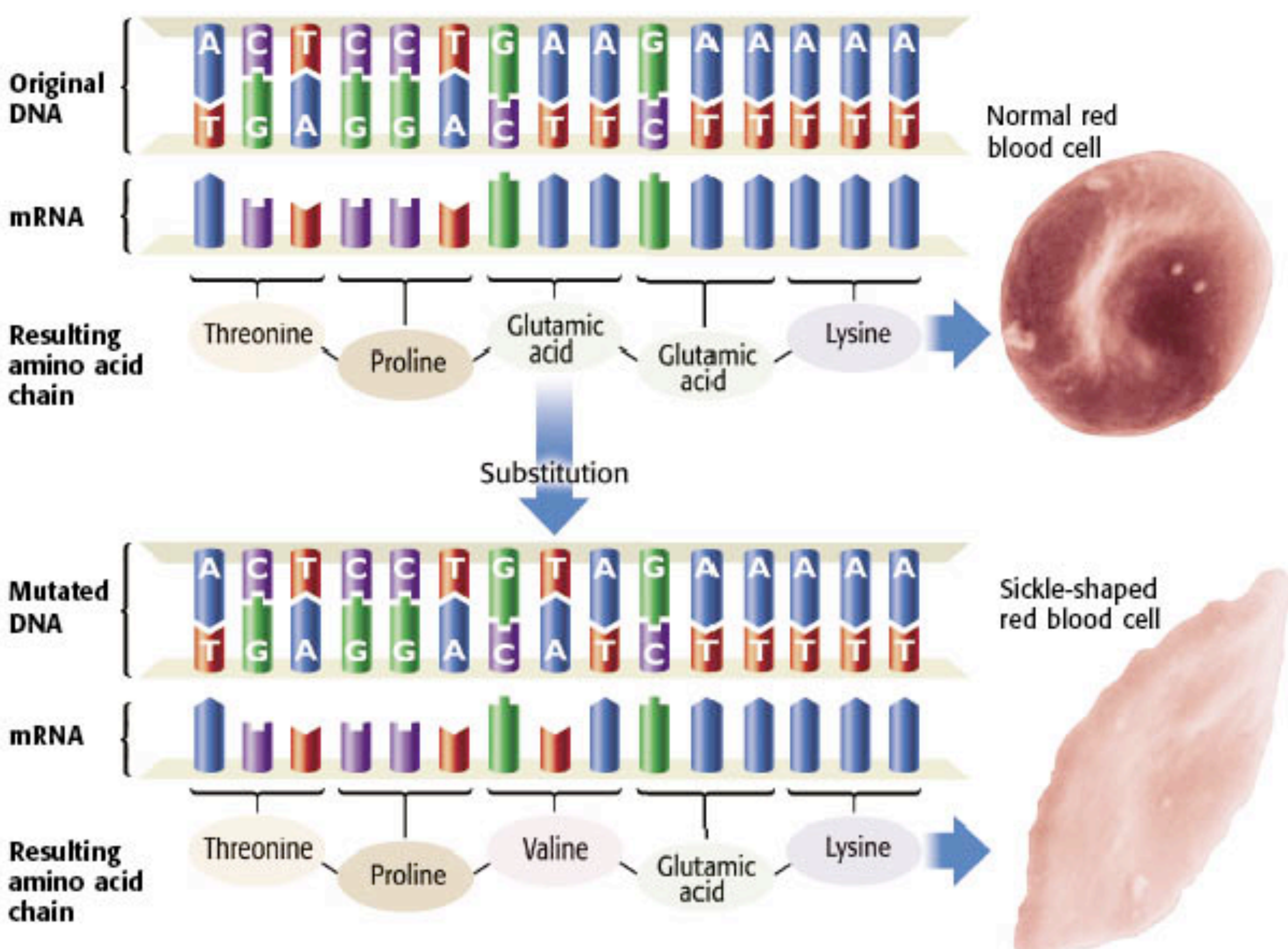
An Error in the Message

The sentence below is the result of an error similar to a DNA mutation. The original sentence was made up of three-letter words, but an error was made in this copy. Explain the idea of mutations to your parent or guardian. Then, work together to find the mutation, and write the sentence correctly.

THE IGB ADC ATA TET HEB IGR EDR AT.

ACTIVITY

Figure 4 **How Sickle Cell Disease Results from a Mutation**



Uses of Genetic Knowledge

In the years since Watson and Crick made their model, scientists have learned a lot about genetics. This knowledge is often used in ways that benefit humans. But some uses of genetic knowledge also cause ethical and scientific debates.

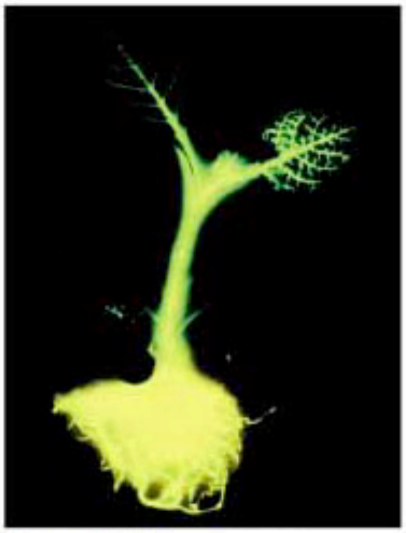


Figure 5 *This genetically engineered tobacco plant contains firefly genes.*

Genetic Engineering

Scientists can manipulate individual genes within organisms. This kind of manipulation is called *genetic engineering*. In some cases, genes may be transferred from one type of organism to another. An example of a genetically engineered plant is shown in **Figure 5.** Scientists added a gene from fireflies to this plant. The gene produces a protein that causes the plant to glow.

Scientists may use genetic engineering to create new products, such as drugs, foods, or fabrics. For example, bacteria may be used to make the proteins found in spider's silk. Or cows may be used to produce human proteins. In some cases, this practice could produce a protein that is needed by a person who has a genetic disease. However, some scientists worry about the dangers of creating genetically engineered organisms.

Genetic Identification

Your DNA is unique, so it can be used like a fingerprint to identify you. *DNA fingerprinting* identifies the unique patterns in an individual's DNA. DNA samples are now used as evidence in crimes, as shown in **Figure 6.** Similarities between people's DNA can reveal other information, too. For example, DNA can be used to identify family relations or hereditary diseases.

Figure 6 *This scientist is gathering dead skin cells from a crime scene. DNA from the cells could be used as evidence of a criminal's identity.*

Identical twins have truly identical DNA. Scientists are now able to create something like a twin, called a clone. A *clone* is a new organism that has an exact copy of another organism's genes. Clones of several types of organisms, including some mammals, have been developed by scientists. However, the possibility of cloning humans is still being debated among both scientists and politicians.

Reading Check **What is a clone?**

CONNECTION TO Social Studies

Genetic Property Could you sell your DNA code? Using current laws and technology, someone could sell genetic information like authors sell books. It is also possible to file a patent to establish ownership of the information used to make a product. Thus, a patent can be filed for a unique sequence of DNA or for new genetic engineering technology. Conduct research to find an existing patent on a genetic sequence or genetic engineering technology.

SECTION Review

Summary

- A gene is a set of instructions for assembling a protein. DNA is the molecular carrier of these genetic instructions.
- Every organism has DNA in its cells. Humans have about 2 m of DNA in each cell.
- Within a gene, each group of three bases codes for one amino acid. A sequence of amino acids is linked to make a protein.
- Proteins are fundamental to the function of cells and the expression of traits.
- Proteins are assembled within the cytoplasm through a multi-step process that is assisted by several forms of RNA.
- Genes can become mutated when the order of the bases is changed. Three main types of mutations are possible: insertion, deletion, and substitution.
- Genetic knowledge has many practical uses. Some applications of genetic knowledge are controversial.

Using Key Terms

1. Use each of the following terms in the same sentence: *ribosome* and *RNA*.
2. In your own words, write a definition for the term *mutation*.

Understanding Key Ideas

3. Explain the relationship between genes and proteins.
4. List three possible types of mutations.
5. Which type of mutation causes sickle cell anemia?
   - a. substitution
   - b. insertion
   - c. deletion
   - d. mutagen

Math Skills

6. A set of 23 chromosomes in a human cell contains 3.2 billion pairs of DNA bases in sequence. On average, about how many pairs of bases are in each chromosome?

Critical Thinking

7. **Applying Concepts** In which cell type might a mutation be passed from generation to generation? Explain.
8. **Making Comparisons** How is genetic engineering different from natural reproduction?

Interpreting Graphics

The illustration below shows a sequence of bases on one strand of a DNA molecule. Use the illustration below to answer the questions that follow.

9. How many amino acids are coded for by the sequence on one side (A) of this DNA strand?
10. What is the order of bases on the complementary side of the strand (B), from left to right?
11. If a G were inserted as the first base on the top side (A), what would the order of bases be on the complementary side (B)?

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For a variety of links related to this chapter, go to www.scilinks.org

Topic: Genetic Engineering
SciLinks code: HSM0654

Chapter Review

USING KEY TERMS

1. Use the following terms in the same sentence: *mutation* and *mutagen*.

The statements below are false. For each statement, replace the underlined term to make a true statement.

2. The information in DNA is coded in the order of amino acids along one side of the DNA molecule.

3. The "factory" that assembles proteins based on the DNA code is called a gene.

UNDERSTANDING KEY IDEAS

Multiple Choice

4. James Watson and Francis Crick
   - **a.** took X-ray pictures of DNA.
   - **b.** discovered that genes are in chromosomes.
   - **c.** bred pea plants to study heredity.
   - **d.** made models to figure out DNA's shape.

5. In a DNA molecule, which of the following bases pair together?
   - **a.** adenine and cytosine
   - **b.** thymine and adenine
   - **c.** thymine and guanine
   - **d.** cytosine and thymine

6. A gene can be all of the following EXCEPT
   - **a.** a set of instructions for a trait.
   - **b.** a complete chromosome.
   - **c.** instructions for making a protein.
   - **d.** a portion of a strand of DNA.

7. Which of the following statements about DNA is NOT true?
   - **a.** DNA is found in all organisms.
   - **b.** DNA is made up of five subunits.
   - **c.** DNA has a structure like a twisted ladder.
   - **d.** Mistakes can be made when DNA is copied.

8. Within the cell, where are proteins assembled?
   - **a.** the cytoplasm
   - **b.** the nucleus
   - **c.** the amino acids
   - **d.** the chromosomes

9. Changes in the type or order of the bases in DNA are called
   - **a.** nucleotides.
   - **b.** mutations.
   - **c.** RNA.
   - **d.** genes.

Short Answer

10. What would be the complementary strand of DNA for the following sequence of bases?

    C T T A G G C T T A C C A

11. If the DNA sequence TGAGCCATGA is changed to TGAGCACATGA, what kind of mutation has occurred?

12. Explain how the DNA in genes relates to the traits of an organism.

13. Why is DNA frequently found associated with proteins inside of cells?

14. What is the difference between DNA and RNA?

CRITICAL THINKING

15. **Concept Mapping** Use the following terms to create a concept map: *bases, adenine, thymine, nucleotides, guanine, DNA*, and *cytosine*.

16. **Analyzing Processes** Draw and label a picture that explains how DNA is copied.

17. **Analyzing Processes** Draw and label a picture that explains how proteins are made.

18. **Applying Concepts** The following DNA sequence codes for how many amino acids?

    T C A G C C A C C T A T G G A

19. **Making Inferences** Why does the government make laws about the use of chemicals that are known to be mutagens?

INTERPRETING GRAPHICS

The illustration below shows the process of replication of a DNA strand. Use this illustration to answer the questions that follow.

20. Which strands are part of the original molecule?
    a. A and B
    b. A and C
    c. A and D
    d. None of the above

21. Which strands are new?
    a. A and B
    b. B and C
    c. C and D
    d. None of the above

22. Which strands are complementary?
    a. A and C
    b. B and C
    c. All of the strands
    d. None of the strands