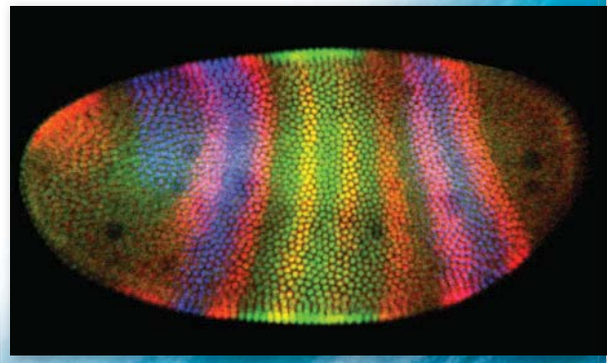
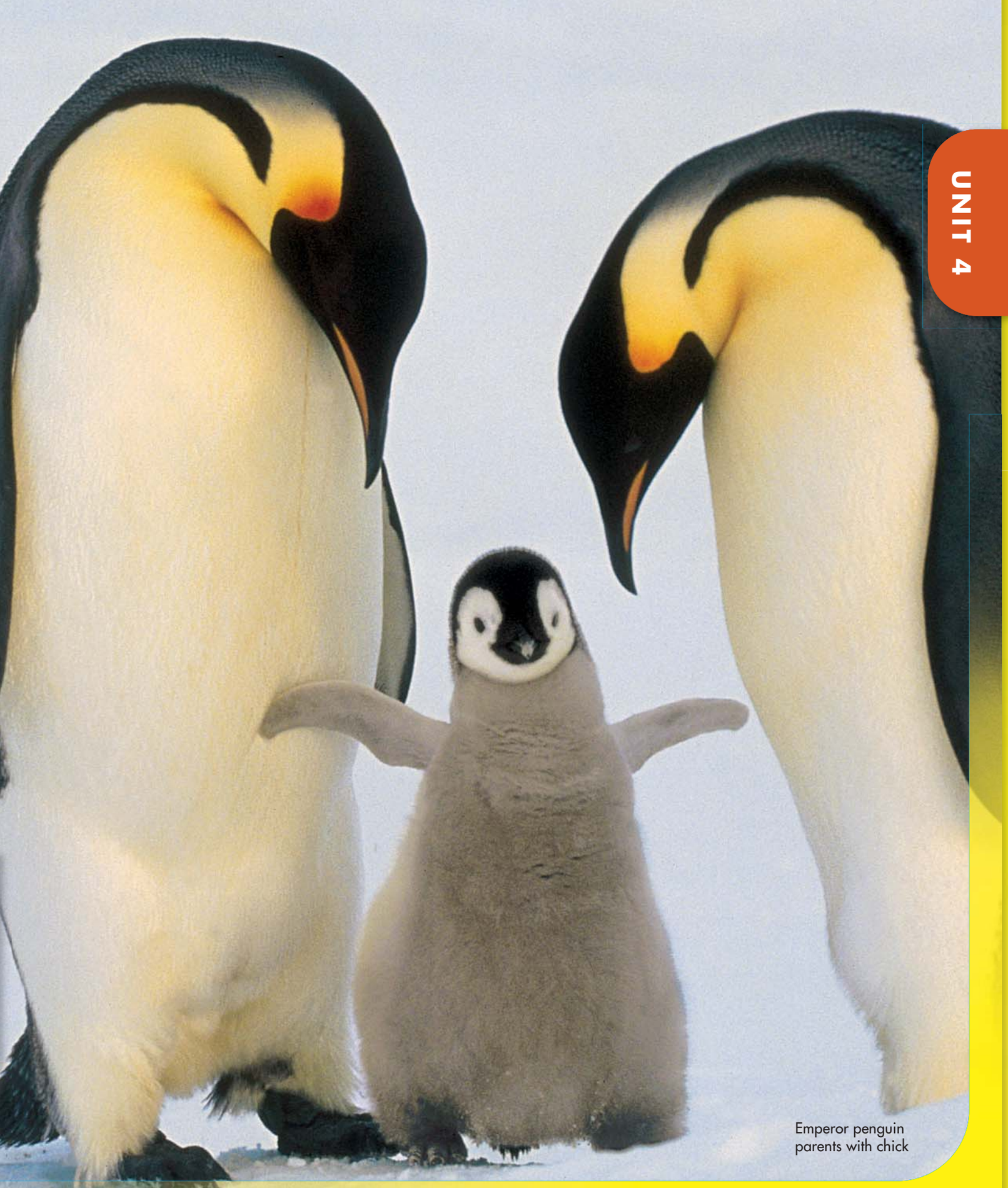
UNIT 4 Heredity

Eggs of the red-eyed tree frog stuck to the underside of a leaf



Fruit fly embryo, marked to show pattern of genes being expressed



Emperor penguin parents with chick

DISCOVERIES IN SCIENCE

Heredity and Genetics

1865

Gregor Mendel publishes the results of his studies of genetic inheritance in pea plants. Although his work is not widely known until much later, Mendel is remembered as the founder of the science of genetics.

Gregor Mendel

1879

After staining cells with Perkins dye and viewing them under a microscope, Walter Fleming identifies chromatin in cells. Soon after, he observes and describes all stages of mitosis, using terms such as *metaphase, anaphase and telophase.*

1905

Nettie Maria Stephens describes how human gender is determined by the X and Y chromosomes.

Nettie Stevens

1909

The Elements of Heredity, by Wilhelm Johannsen, a Danish biologist, is revised and translated into German. In the book, Johannsen develops many of the concepts of modern genetics, particularly phenotype and genotype. This book becomes a founding text of genetics.

1913

Alfred Henry Sturtevant, an undergraduate student at Columbia University, determines the relative location of genes on a fruit fly chromosome. He publishes a genetic map showing the order of genes and their relative distance from each other.

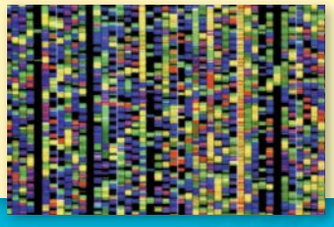
1915

Thomas Hunt publishes the book *Mechanism of Mendelian Heredity,* which explains the phenomenon of sex-linked traits observed in fruit flies.

***Drosophila melanogaster* (fruit fly)**

1989

Francis Collins and Lap-Chee Tsui identify a mutant version of a gene on chromosome 7 that causes cystic fibrosis. Discovery of the gene leads to the development of tests that can determine whether potential parents are carriers of the gene.

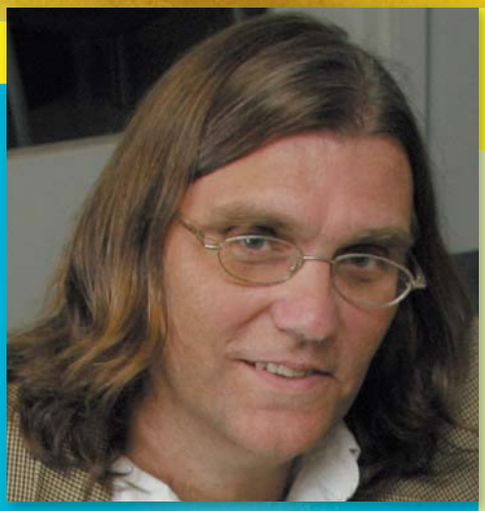


Genetic sequences on a computer screen

2003

The Human Genome Project is completed. Research teams around the world collaborated to identify all genes and decode the sequence of all DNA in human cells.

Albino peacock



BIOLOGY CAREER

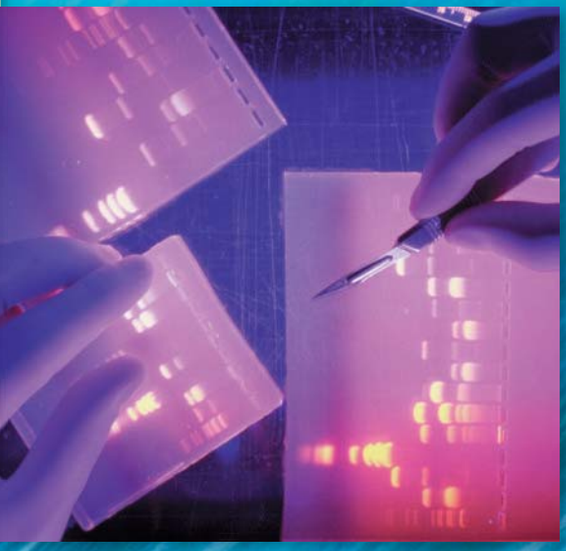
Genetics Researcher

Rob Desalle

Rob DeSalle is a curator in the Division of Invertebrate Zoology at the American Museum of Natural History in New York City. His current research focuses on molecular evolution in a variety of organisms, including pathogenic bacteria and insects.

DeSalle studies molecular evolution through comparative genomics, which is the study of similarities and differences between the genomes of various species or strains within species. Comparing the genomes of species can help determine how the species are related.

DeSalle also helped found the Conservation Genetics Program at the American Museum of Natural History. This program uses the tools of molecular genetics to help protect wildlife around the world. For example, DeSalle helped develop a genetic test to determine if caviar sold in the United States was illegally harvested from endangered species of sturgeon in the Caspian Sea.



Genetic analysis by gel electrophoresis

UNIT 4

Chapter Planner

13

DNA, RNA, and Proteins

		Standards	Teach Key Ideas
CHAPTER OPENER, pp. 290–291	15 min.	*National Science Education Standards*	
SECTION 1 The Structure of DNA, pp. 293–299 › DNA: The Genetic Material › Searching for the Genetic Material › The Shape of DNA › The Information in DNA › Discovering DNA's Structure	90 min.	LSCell 1, LSCell 2, LSCell 3, LSCell 4, LSGene 1, LSGene 2, UCP2, HNS2, HNS3	**Bellringer Transparencies** **Transparencies** C9 Griffith's Discovery of Transformation • C10 The Hershey-Chase Experiment • C11 DNA Double Helix **Visual Concepts** Transformation • Hershey and Chase's Experiment • Bacteriophage • DNA Overview • Double Helix • Nucleotide • Structure of a Nucleotide • Comparing Purines and Pyrimidines • Complementary Base Pairing
SECTION 2 Replication of DNA, pp. 300–303 › DNA Replication › Replication Proteins › Prokaryotic and Eukaryotic Replication	60 min.	LSCell 1, LSCell 2, LSCell 3, LSCell 4, LSGene 1, LSGene 3, UCP1, UCP5, SPSP5	**Bellringer Transparencies** **Transparencies** C12 DNA Replication • C13 Replication Forks **Visual Concepts** DNA Replication • Snapshots of Replication • Replication Forks Increase the Speed of Replication
SECTION 3 RNA and Gene Expression, pp. 304–310 › An Overview of Gene Expression › RNA: A Major Player › Transcription: Reading the Gene › The Genetic Code: Three-Letter "Words" › Translation: RNA to Proteins › Complexities of Gene Expression	60 min.	LSCell 1, LSCell 2, LSCell 3, LSCell 4, LSGene 1, UCP1, UCP5, ST2, SPSP1, SPSP6, HNS1	**Bellringer Transparencies** **Transparencies** C15 Transcription • C16 Codons in mRNA • C17 Translation: Assembling Proteins **Visual Concepts** Ribonucleic Acid • Comparing DNA and RNA • Gene Expression • Transcription • Promoter• Codons in mRNA • Genetic Code • tRNA and Anticodon • Translation • Snapshot of Translation • Ribosomes
			See also PowerPoint® Resources

Chapter Review and Assessment Resources

- SE Super Summary, p. 312
- SE Chapter Review, p. 313
- SE Standardized Test Prep, 315
- Review Resources
- Chapter Tests A and B
- Holt Online Assessment

CHAPTER **FastTrack**

To shorten instruction due to time limitations, eliminate the Skills Practice Lab: DNA Extraction.

Basic Learners

- TE Organizing Concepts, p. 294
- TE Replication Model, p. 301
- TE Recognizing the Code, p. 306
- Directed Reading Worksheets*
- Active Reading Worksheets*
- Lab Manuals, Level A*
- Study Guide* ■
- Note-taking Workbook*
- Special Needs Activities and Modified Tests*

Advanced Learners

- TE Genetics in the News, pg. 298
- Critical Thinking Worksheets*
- Concept Mapping Worksheets*
- Science Skills Worksheets*
- Lab Datasheets, Level C*

Key

SE Student Edition
TE Teacher's Edition
Chapter Resource File
Workbook
Transparency
CD or CD-ROM
* Datasheet or blackline master available
■ Also available in Spanish

All resources listed below are also available on the Teacher's One-Stop Planner.

Why It Matters	Hands-On	Skills Development	Assessment
Build student motivation with resources about high-interest applications.	SE **Inquiry Lab** Code Combinations, p. 291	TE **Reading Toolbox** Assessing Prior Knowledge, p. 290 SE **Reading Toolbox,** p. 292	
TE **Why Protein?,** p. 293 TE **The Importance of Molecular Shape,** p. 296 TE **Demonstration** The Shape of DNA, p. 296 TE **Crediting Rosalind Franklin,** p. 298	SE **Quick Lab** DNA's Structure, p. 297 SE **Skills Practice Lab** DNA Extraction from Wheat Germ, p. 311 **Exploration Lab** Extracting DNA*	SE **Reading Toolbox** Describing Time, p. 294 TE **Reading Toolbox** Scientific Illustrations, p. 294 TE **Reading Toolbox** Visual Literacy, p. 294 TE **Reading Toolbox** Visual Literacy, p.295 TE **Reading Toolbox** Visual Literacy, p.298	SE **Section Review** TE **Formative Assessment** **Spanish Assessment*** ■ **Section Quiz** ■
	SE **Quick Lab** DNA Replication Rate, p. 303 **Skills Practice Lab** Karyotyping: Genetic Disorders*	SE **Reading Toolbox** Visual Literacy, p. 300 TE **Reading Toolbox** Visual Literacy, p. 301 SE **Reading Toolbox** Word Parts, p. 302 TE **Reading Toolbox** Word Parts, p. 302 TE **Reading Toolbox** Visual Literacy, p. 302	SE **Section Review** TE **Formative Assessment** **Spanish Assessment*** ■ **Section Quiz** ■
TE **Redundant Condons,** p. 307 TE **Antibiotic Function,** p. 308 TE **Polyribosomes,** p. 309	SE **Quick Lab** Genetic Code of Keratin, p. 310	TE **Reading Toolbox** Word Parts, p. 305 SE **Reading Toolbox** Three-Panel Flip Chart, p. 306 TE **Reading Toolbox** Three-Panel Flip Chart, p. 306 TE **Reading Toolbox** Visual Literacy, p. 307 TE **Reading Toolbox** Visual Literacy, p. 308 TE **Reading Toolbox** Visual Literacy, p. 309	SE **Section Review** TE **Formative Assessment** **Spanish Assessment*** ■ **Section Quiz** ■
	See also Lab Generator		**See also Holt Online Assessment Resources**

Resources for Differentiated Instruction

English Learners

TE Genes, Proteins, and DNA, p. 305
TE RNA Pairing Rules, p. 306
Directed Reading Worksheets*
Active Reading Worksheets*
Lab Manuals, Level A*
Study Guide* ■
Note-taking Workbook*
Multilingual Glossary

Struggling Readers

TE Deciphering Symbols, p. 295
Directed Reading Worksheets*
Active Reading Worksheets*
Lab Manuals, Level A*
Study Guide*
Note-taking Workbook*
Special Needs Activities and Modified Tests*

Special Education Students

Replication Fork Model, p. 302
Directed Reading Worksheets*
Active Reading Worksheets*
Lab Manuals, Level A*
Study Guide* ■
Note-taking Workbook*
Special Needs Activities and Modified Tests*

Alternative Assessment

TE Replication, p. 305
TE Translation, p. 309
Science Skills Worksheets*
Section Quizzes* ■
Chapter Tests A, B, and C* ■

Chapter 13

Overview

The purpose of this chapter is to explain the universal nature of DNA and its importance to life on Earth. The research that led to the discovery of DNA is an example of how the accumulation of information gathered from scientific processes adds to the body of information we call science. The nature of the DNA molecule makes it possible for it to replicate itself, but more importantly, it has the code needed to direct the assembly of amino acids into polypeptides. Another nucleic acid, RNA, facilitates this process of gene expression.

READING TOOLBOX

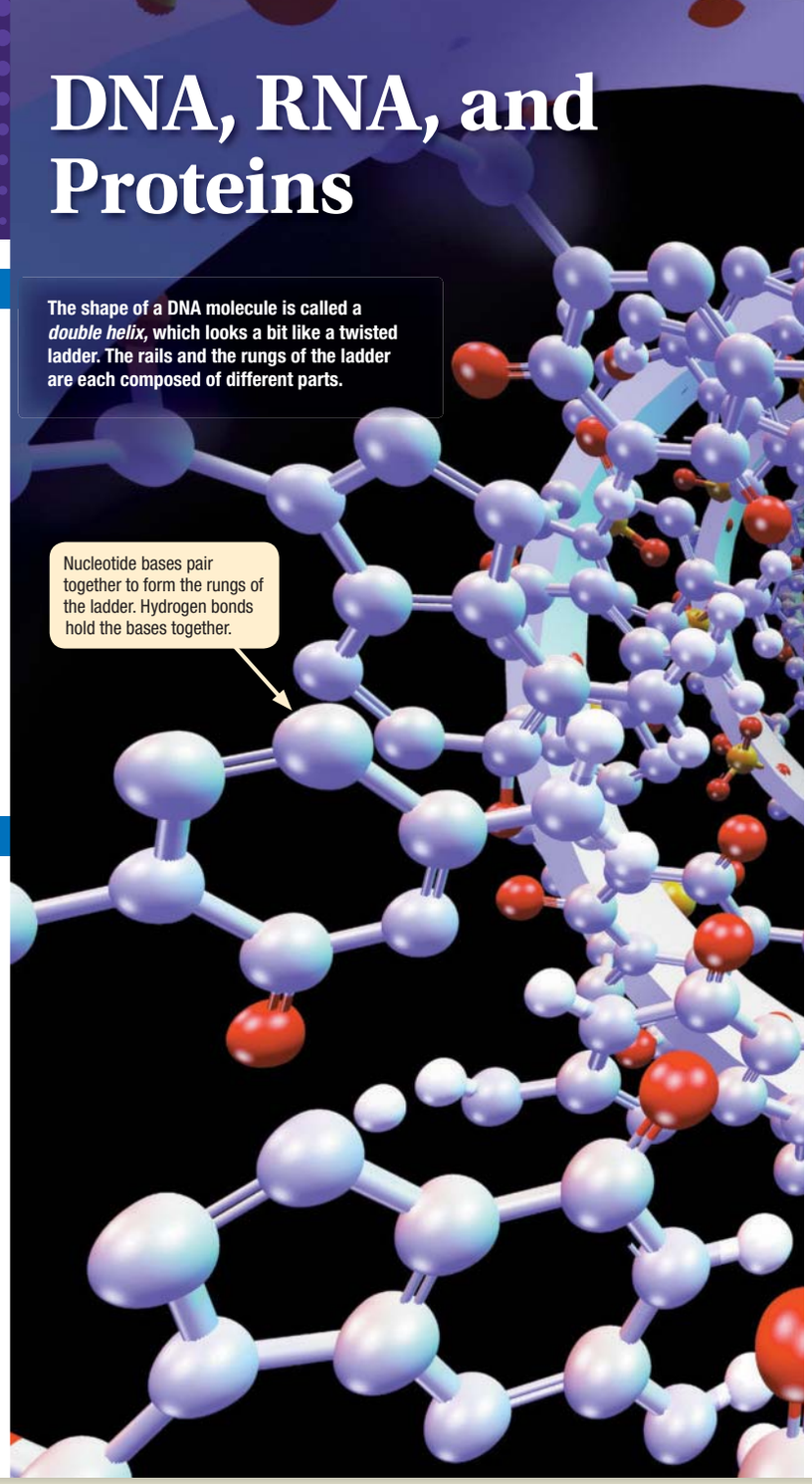
Assessing Prior Knowledge Students should understand the following concepts:

- structural characteristics of basic biomolecules
- cell structure and function

Visual Literacy Ask students to define the term *model* as it applies to this photograph. (It's a description used to help visualize something that cannot be seen.) Ask students why the parts of the model are different sizes. (Some parts are closer, and others are farther away in the part that is coiled) Explain that this photo shows only a fraction of a typical DNA molecule.

Chapter 13

DNA, RNA, and Proteins



Preview

Why It Matters

Did you know that DNA is found in the cells of all organisms? A unique set of genes makes one organism different from another, but DNA is the universal molecule found in all genes.

Chapter Correlations

National Science Education Standards

LSCell 1 Cells have particular structures that underlie their functions.

LSCell 2 Most cell functions involve chemical reaction.

LSCell 3 Cells store and use information to guide their functions.

LSCell 4 Cell functions are regulated.

LSGene 1 In all organisms, the instructions for specifying the characteristics of the organisms are carried in DNA.

LSGene 2 Most of the cells in a human contain two copies of each of 22 different chromosomes. In addition there is a pair of chromosomes that determine sex.

LSGene 3 Changes in DNA (mutations) occur spontaneously at low rates.

UCP1 Systems, order, and organization

UCP2 Evidence, models, and explanation

UCP5 Form and function

ST2 Understandings about science and technology

SPSP1 Personal and community health

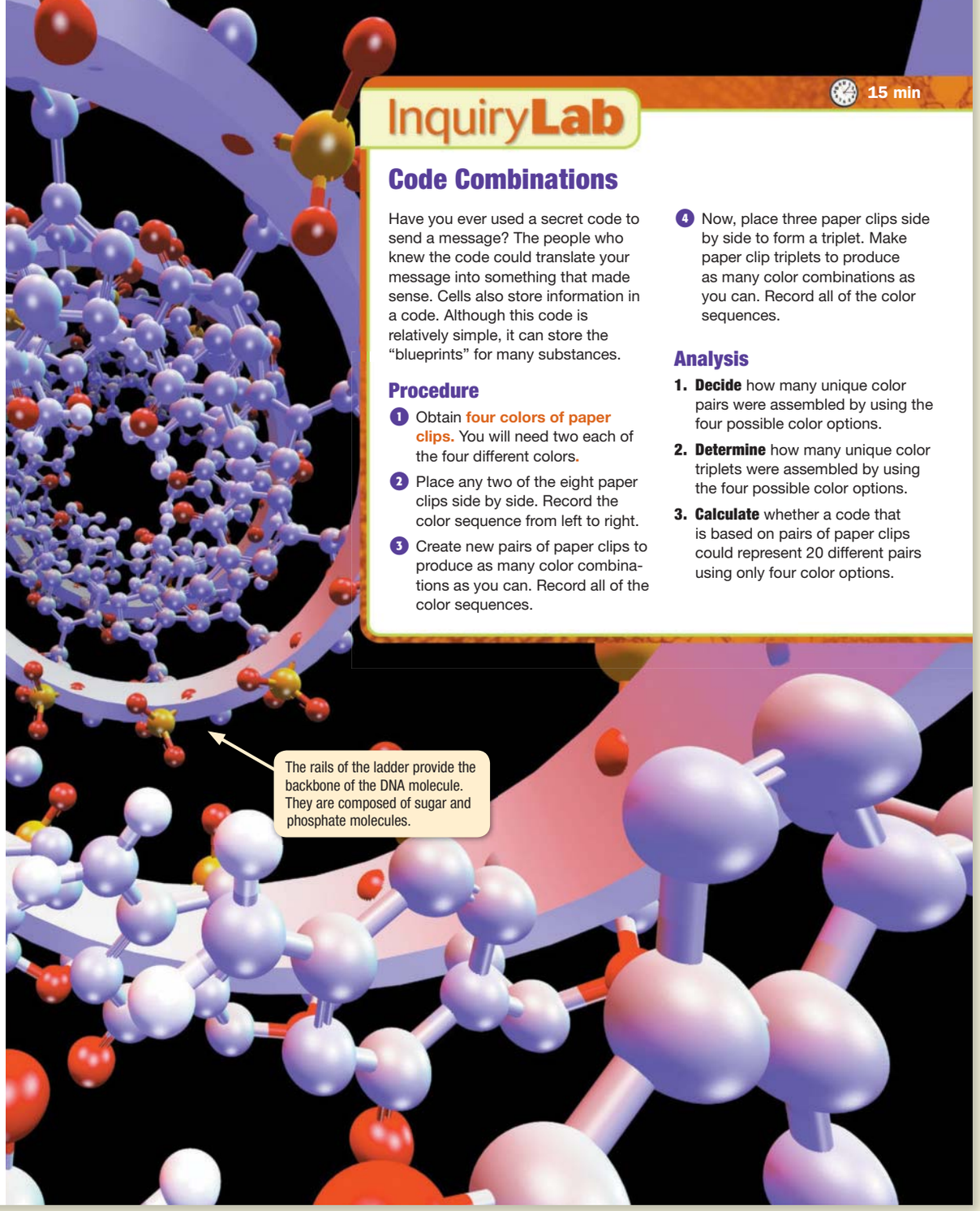
SPSP5 Natural and human-induced hazards

SPSP6 Science and technology in local, national, and global challenges

HNS1 Science as a human endeavor

HNS2 Nature of scientific knowledge

HNS3 Historical perspectives



15 min

InquiryLab

Code Combinations

Have you ever used a secret code to send a message? The people who knew the code could translate your message into something that made sense. Cells also store information in a code. Although this code is relatively simple, it can store the "blueprints" for many substances.

Procedure

1. Obtain **four colors of paper clips.** You will need two each of the four different colors.
2. Place any two of the eight paper clips side by side. Record the color sequence from left to right.
3. Create new pairs of paper clips to produce as many color combinations as you can. Record all of the color sequences.
4. Now, place three paper clips side by side to form a triplet. Make paper clip triplets to produce as many color combinations as you can. Record all of the color sequences.

Analysis

1. **Decide** how many unique color pairs were assembled by using the four possible color options.
2. **Determine** how many unique color triplets were assembled by using the four possible color options.
3. **Calculate** whether a code that is based on pairs of paper clips could represent 20 different pairs using only four color options.

InquiryLab

Teacher's Notes This lab establishes the importance of the triplet code composed of three of the four nitrogen bases to correctly specify all twenty amino acids. Students should record all color sequences; green-red (G-R) is not the same as red-green (R-G).

Materials

- paper clips (8, 2 each of 4 different colors)

Answers to Analysis

1. There are sixteen possible combinations using two-colored clips.
2. There are sixty-four possible combinations using three-colored clips. Some students may not find all these combinations, but they should have more than twenty.
3. A code based on *pairs* of paper clips is not sufficient to represent twenty separate items.

Key Resources

Interactive Tutor

READING TOOLBOX

Using Words

1. helicopter
2. A bacterium of this genus should be spiral shaped.
3. Answers will vary, but students should convey the idea that a bacteriophage is a virus that infects bacteria.

Using Language

1. before the sun rises
2. first

Using FoldNotes

Check to see that students have accurately followed the directions.

READING TOOLBOX

These reading tools can help you learn the material in this chapter. For more information on how to use these and other tools, see **Appendix: Reading and Study Skills.**

Using Words

Word Parts Knowing the meanings of word parts can help you figure out the meanings of unknown words.

Word Parts

Part	Type	Meaning
bacterio	root	involving bacteria
helic	root	spiral
-ase	suffix	enzyme
phage	root	to eat or destroy

Your Turn Use the table to answer the following questions.

1. The root *-ptera* means "wing." What familiar machine is named for its spiral wing?
2. *Helicobacter* is a genus of bacteria. What shape is a bacterium of this genus?
3. In your own words, write a definition for *bacteriophage*.

Using Language

Describing Time Certain words and phrases can help you understand when something happened and how long it took. These words and phrases are called *specific time markers*. Specific time markers include words and phrases such as *first, next, 1 hour, yesterday, the twentieth century,* and *30 years later.*

Your Turn Read the sentences below and write down the specific time markers.

1. Early in the morning, before the sun rises, Emilio gets up to take his dogs for a walk.
2. Before a cell can divide, it must first make a copy of its DNA.

Using FoldNotes

Three-Panel Flip Chart A three-panel flip chart is useful when you want to organize notes about three topics. It can help you organize the characteristics of the topics side by side.

Your Turn Make a three-panel flip chart to organize your notes about DNA structure and replication.

1. Fold a piece of paper in half from the top to the bottom.
2. Fold the paper in three sections from side to side. Unfold the paper so that you can see the three sections.
3. From the top of the paper, cut along the vertical fold lines to the fold in the middle of the paper. You will now have three flaps.
4. Label the flaps of the three-panel flip chart "Identifying the Genetic Material," "The Structure of DNA," and "The Replication of DNA."
5. Under each flap, write your notes about the appropriate topic.

Section 1

The Structure of DNA

Key Ideas	Key Terms	Why It Matters
❯ What is genetic material composed of? ❯ What experiments helped identify the role of DNA? ❯ What is the shape of a DNA molecule? ❯ How is information organized in a DNA molecule? ❯ What scientific investigations led to the discovery of DNA's structure?	gene DNA nucleotide purine pyrimidine	DNA is the "blueprint" from which all living things are made, so understanding DNA is key to understanding life.

Unless you have an identical twin, you—like the sisters in **Figure 1**—share some, but not all, characteristics with family members.

DNA: The Genetic Material

In the 1800s, Gregor Mendel showed that traits are passed from parents to offspring. Many years later, scientists have discovered how these traits are passed on. The instructions for inherited traits are called **genes.** Before the 1950s, however, scientists did not know what genes were made of. We now know that genes are made of small segments of deoxyribonucleic acid, or **DNA.** ❯ **DNA is the primary material that causes recognizable, inheritable characteristics in related groups of organisms.**

DNA is a relatively simple molecule, composed of only four different subunits. For this reason, many early scientists did not consider DNA to be complex enough to be genetic material. A few key experiments led to the discovery that DNA is, in fact, genetic material.

❯ **Reading Check** ***What are genes composed of? (See Appendix for answers to Reading Checks.)***

gene a segment of DNA that is located in a chromosome and that codes for a specific hereditary trait

DNA deoxyribonucleic acid, the material that contains the information that determines inherited characteristics

Figure 1 These sisters share many traits but also have differences. ❯ **What role do genes play in passing traits from parents to offspring?**

Why It Matters

Why Protein? Most scientists thought that genes must be made of protein because protein is more complex than other biological molecules known at the time. Because proteins are made of many different amino acids, they were thought to be the only molecules complex enough to carry information for the huge variety of traits controlled by genes. LS **Logical**

Key Resources

Transparencies
- C9 Griffith's Discovery of Transformation
- C10 The Hershey-Chase Experiment
- C11 DNA Double Helix

Visual Concepts
- Transformation
- Hershey and Chase's Experiments
- Bacteriophage
- DNA Overview
- Double Helix
- Nucleotide
- Structure of a Nucleotide
- Comparing Purines and Pyrimidines
- Complementary Base Pairing

Section 1

Focus

This section explains the contributions of Griffith, Avery, Hershey, and Chase, which led to the conclusion that DNA, not a protein was the molecule of heredity. It is a good example of how science builds on the work of other scientists, utilizing the scientific method.

Bellringer

Use the Bellringer transparency to prepare students for this section.

Teach

Teaching Key Ideas

Mendel's Legacy Ask the students to recall that Mendel determined factors that enabled instructions for traits to pass from one generation to the next. However, no one really knew the composition of these "factors." Scientists wanted to find out what the blueprint was. Ask students to describe the functions of a blueprint, using examples. Record their answers and post them, so at the end of the chapter, they can refer to these functions and compare them to those of DNA. LS **Verbal**

Answers to Caption Questions

Figure 1: Genes contain the information that enables traits to be passed from parents to offspring.

Teach, *continued*

READING TOOLBOX

Describing Time Sample answer: *First,* Griffith determines that live *S* bacteria cause mice to die. The *R* bacteria are harmless (mice do not die). *Then,* Griffith mixes live *R* bacteria with dead S bacteria and the mice die. He *then* concludes that a transformation has occurred. LS **Visual and Logical**

READING TOOLBOX

Visual Literacy Have students draw Avery's experiment. Have them fold a paper in half vertically. Have them draw an *S* bacterial cell at the top of each column. Label the protein capsule on the *S* bacterium and label the DNA on the interior. Use different colored pencils to represent each of the two enzymes. On the left side, color the protein coat and draw an arrow below to show R bacteria are dead ("x" out) and not transformed. On the right side, color the DNA only. Draw an arrow below to show that R cells are not transformed, but are still alive. LS **Visual**

Answers to Caption Questions

Figure 2: The independent variable was the type of bacteria injected into the mouse (S bacteria vs. R bacteria) and the dependent variable was mortality rate (whether or not the mouse would die after injection) in Griffith's experiment.

Searching for the Genetic Material

Once scientists discovered DNA, they began to search for its location. By the 1900s, scientists had determined that genetic material was located in cells, but they did not know exactly where. **Three major experiments led to the conclusion that DNA is the genetic material in cells. These experiments were performed by Griffith, Avery, Hershey, and Chase.**

Griffith's Discovery of Transformation In 1928, Frederick Griffith was working with two related strains of bacteria. The S strain causes pneumonia and is covered by a capsule of polysaccharides. The R strain has no capsule and does not cause pneumonia. Mice that are infected with the S bacteria get sick and die. Griffith injected mice with heat-killed S bacteria. The bacteria were dead, but the capsule was still present. The mice lived. Griffith concluded that the S bacteria cause disease.

However, when harmless, live R bacteria were mixed with the harmless, heat-killed S bacteria and were injected into mice, the mice died. Griffith had discovered *transformation,* which is a change in genotype that is caused when cells take up foreign genetic material. Griffith's experiments, shown in **Figure 2,** led to the conclusion that genetic material could be transferred between cells. But no one knew that this material was DNA.

READING TOOLBOX

Describing Time Use specific time markers and **Figure 2** to describe Griffith's experiment.

Avery's Experiments with Nucleic Acids In the 1940s, Oswald Avery wanted to determine whether the transforming agent in Griffith's experiments was protein, RNA, or DNA. Avery and his colleagues used enzymes to destroy each of these molecules in heat-killed S bacteria. They found that bacteria that were missing protein and RNA were able to transform R cells into S cells. However, bacteria that were missing DNA did not transform R cells. The scientists concluded that DNA is responsible for transformation in bacteria.

In 1952, Alfred Hershey and Martha Chase thought that they could support Avery's conclusions by showing how DNA and proteins cross the cell membrane. Their experiment would determine how DNA affected other cells.

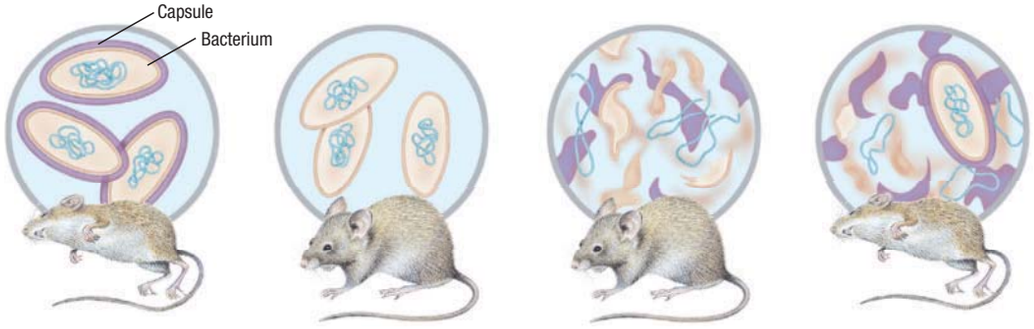


Figure 2 Griffith discovered that harmless bacteria could cause disease when they were mixed with killed disease-causing bacteria. **What were the variables in Griffith's experiments?**

Differentiated Instruction

Basic Learners

Organizing Concepts Have students make posters that give a visual interpretation of Griffith's experiment, showing the heat-killing process, and injections. Check their drawings for accuracy. LS **Visual**

go.hrw.com
interact online
Keyword: HX8DNAF3

Hershey-Chase Experiment

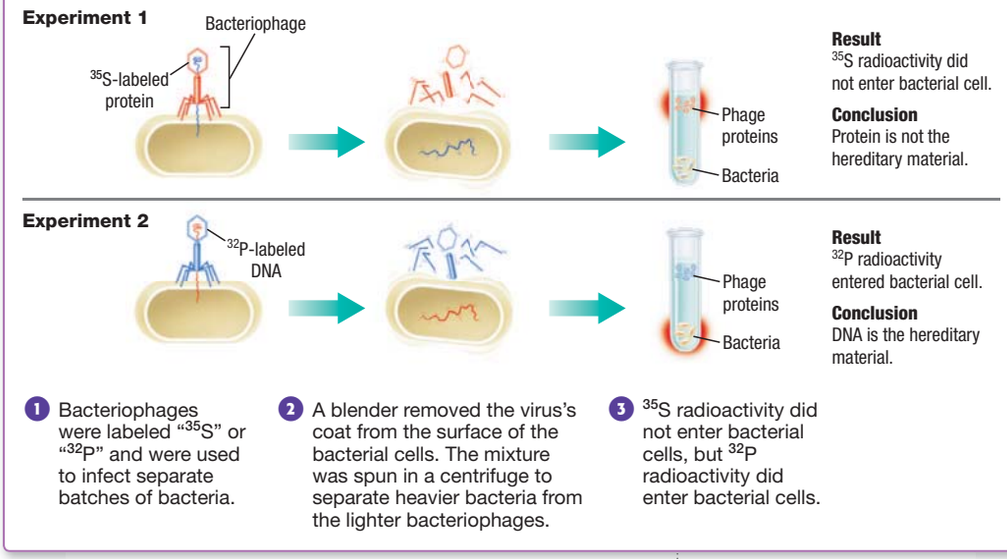


Figure 3 Bacteriophages were used to show that DNA, not protein, is the genetic material in viruses.

Hershey-Chase Experiment Hershey and Chase studied bacteriophages, viruses that infect bacterial cells and cause the cells to produce viruses. Bacteriophages are made up of proteins and DNA, but which of these two molecules is the genetic material in viruses? **Figure 3** illustrates their experiment.

Step 1 First, Hershey and Chase knew that proteins contain some sulfur but no phosphorus and that DNA contains phosphorus but no sulfur. The scientists grew two sets of viruses in environments that were enriched with different radioactive isotopes. One set of viruses had radioactive sulfur (^{35}S) atoms attached to proteins. The other set had radioactive phosphorus (^{32}P) atoms attached to DNA.

Step 2 Second, each set of viruses was allowed to infect separate batches of nonradioactive bacteria. Because radioactive elements release particles that can be detected with machines, they can be tracked in a biological process. Each of the batches was then separated into parts that contained only bacteria or only viruses.

Step 3 The infected bacteria from the ^{35}S batch did not contain radioactive sulfur, so proteins could not have infected the bacteria. However, the infected bacteria from the ^{32}P batch did contain radioactive phosphorus. DNA had infected the bacteria.

Hershey and Chase concluded that only the DNA of viruses is injected into bacterial cells. The injected DNA caused the bacteria to produce viral DNA and proteins. This finding indicated that rather than proteins, DNA is the hereditary material, at least in viruses.

go.hrw.com
interact online

Students can interact with the "Hershey–Chase Experiment" by going to go.hrw.com and typing in the keyword HX8DNAF3.

Teaching Key Ideas

Radioactive Tracers Radioactive elements have unstable nuclei that emit particles to become stable. These particles can be detected by instruments, so their presence in a part of a molecule can be traced. Sulfur is found in protein and phosphorous is in DNA, so these radioactive elements were used in this experiment.

READING TOOLBOX

Visual Literacy Draw **Figure 3** on the board. Have five student volunteers to go to the board to color/identify the part of phage that would contain radioactive sulfur, ^{35}S in Experiment 1, and radioactive phosphorous, ^{32}P in Experiment 2. Have students predict where the ^{35}S and ^{32}P would be in Step 2. (*outside* in Experiment 1 and *inside* in Experiment 2.) Have students refer to **Figure 3** and identify the locations for the radioactive sulfur and phosphorus in the test tubes. LS Visual

Differentiated Instruction

Struggling Readers

Deciphering Symbols Some students will have trouble following the steps of the Hershey-Chase experiment because the isotope symbols pose an additional challenge. Have students substitute common names or colors for the symbols to make the process easier for them to follow while reading.

Teach, *continued*

Teaching Key Ideas

Demonstration

The Shape of DNA Use a model of DNA as students look at **Figure 4.** If possible, show the model untwisted. Call attention to the ladder or staircase shape. Ask what substances make up the sides, or *rails*? (phosphates and deoxyribose sugars) What substances make up the center/steps? (nitrogen bases) What holds the nitrogen bases and the two strands together? (hydrogen bonds)

Now call students' attention to the two side strands of the molecule shown in **Figure 4.** Ask students, "What subunits make up these strands?" (nucleotides) "What parts of each nucleotide are the same?" (sugar and phosphate) "What parts are different?" (nitrogen bases) "How many nitrogen bases are there?" (four) "Are the nitrogen bases the same in appearance; What's different?" (some have one ring, some have two) "How does the arrangement of bases affect the shape of the molecule?" (A double-ringed base is always paired with a single-ringed base.) Conclude the demonstration by twisting the staircase or ladder, to form a double helix. Have students identify this shape. LS Visual

SCILINKS
www.scilinks.org
Topic: DNA
Code: HX80418

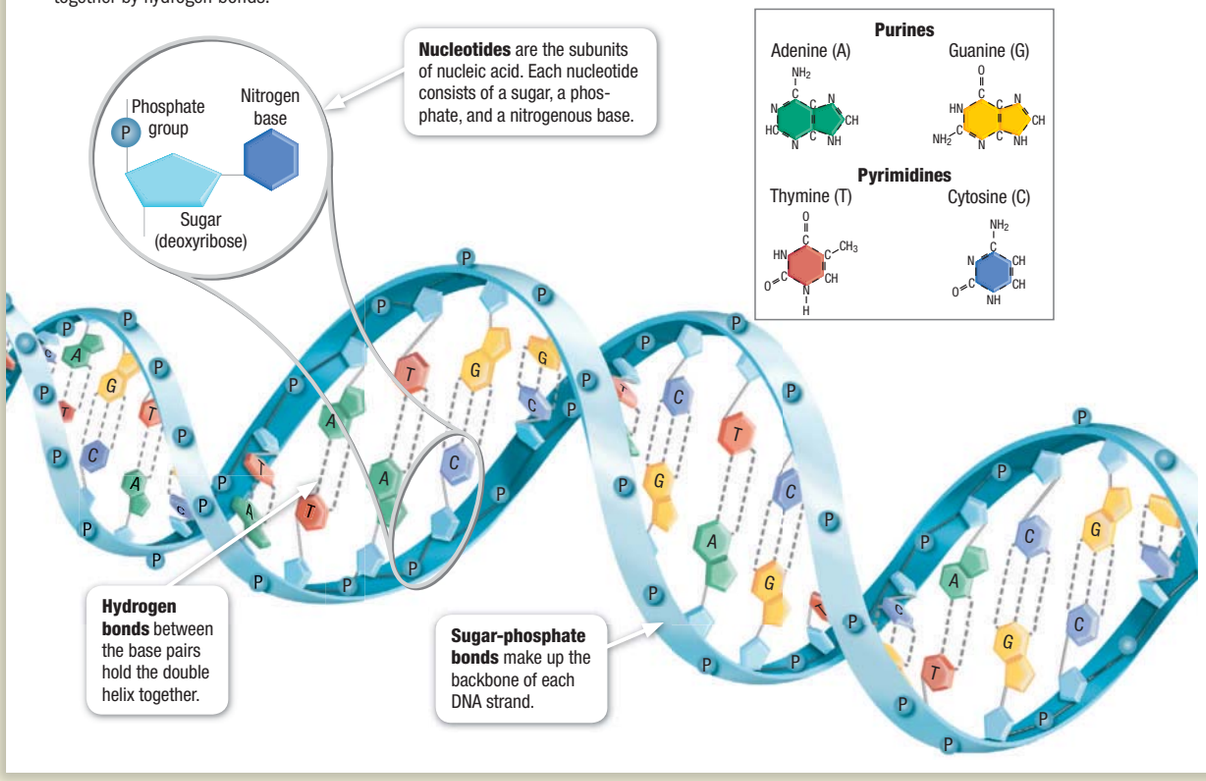
The Shape of DNA

After the important experiments in the early 1950s, most scientists were convinced that genes were made of DNA, but nothing was known about DNA's structure. The research of many scientists led James Watson and Francis Crick, two young researchers at Cambridge University, to piece together a model of DNA's structure. Knowing the structure of DNA allowed scientists to understand how DNA could serve as genetic material.

A Winding Staircase **A DNA molecule is shaped like a spiral staircase and is composed of two parallel strands of linked subunits.** This spiral shape is known as a *double helix,* as **Figure 4** shows. Each strand is made up of linked subunits called nucleotides.

Parts of the Nucleotide Subunits Each **nucleotide** is made up of three parts: a phosphate group, a five-carbon sugar molecule, and a nitrogen-containing base. **Figure 4** shows how these three parts are arranged to form a nucleotide. The phosphate groups and the sugar molecules of nucleotides link together to form a "backbone" for a DNA strand. The five-carbon sugar in DNA is called *deoxyribose*, from which DNA gets its full name, *deoxyribonucleic acid.* The bases of nucleotides pair together to connect the two strands.

Figure 4 Watson and Crick's model of DNA is a double helix that is composed of two nucleotide chains. The chains are twisted around a central axis and are held together by hydrogen bonds.



Why It Matters

The Importance of Molecular Shape When double-ringed bases are paired with single-ringed bases, the steps of the ladder or staircase have a consistent width. Ask students to imagine the stability of a ladder with adjacent steps of varying widths. LS Visual

Hands-On

QuickLab

15 min

DNA's Structure

Build a model to help you understand the structure of DNA.

Procedure

1. Use the following materials to build a model of DNA: **plastic straws** cut into 3 cm sections, a **metric ruler, scissors, pushpins (four different colors),** and **paper clips.** Your model should have at least 12 nucleotides on each strand.
2. As you design your model, decide how to use the straws, pushpins, and paper clips to represent the three components of a nucleotide and how to link the nucleotides together.

Analysis

1. **Describe** your model by using words or drawings. Are the two strands in your model identical? Explain why or why not.
2. **Explain** how you determined which nucleotides were placed on each strand of DNA in your model.
3. CRITICAL THINKING **Inferring Relationships** How might the structure of DNA be beneficial when a cell copies its DNA before cell division?

The Information in DNA

The structure of DNA is very important in the transfer of genetic information. **The information in DNA is contained in the order of the bases, while the base-pairing structure allows the information to be copied.**

Nitrogenous Bases In DNA, each nucleotide has the same sugar molecule and phosphate group, but the nucleotide can have one of four nitrogenous bases. The four kinds of bases, shown in **Figure 4,** are *adenine* (A), *guanine* (G), *thymine* (T), and *cytosine* (C). Bases A and G are classified as **purines.** Purines have two rings of carbon and nitrogen atoms per base. Bases T and C are **pyrimidines.** Pyrimidines have one ring of carbon and nitrogen atoms per base.

Base-Pairing Rules A purine on one strand of a DNA molecule is always paired with a pyrimidine on the other strand. More specifically, adenine always pairs with thymine, and guanine always pairs with cytosine. These *base-pairing rules* are dictated by the chemical structure of the bases. The structure and size of the nitrogenous bases allow for only these two pair combinations. The base pairs are held together by weak hydrogen bonds. Adenine forms two hydrogen bonds with thymine, while cytosine forms three hydrogen bonds with guanine. The hydrogen bonds are represented by dashed lines in **Figure 4.** The hydrogen bonds between bases keep the two strands of DNA together.

Reading Check *How are base-pairs held together?*

nucleotide (NOO klee oh TIED) in a nucleic acid chain, a subunit that consists of a sugar, a phosphate, and a nitrogenous base

purine (PYOOR EEN) a nitrogenous base that has a double-ring structure; adenine or guanine

pyrimidine (pi RIM uh DEEN) a nitrogenous base that has a single-ring structure; in DNA, either thymine or cytosine

QuickLab

Teacher's Notes Let students know that they might need more or less of the colored components depending on the sequence they choose.

Materials
- metric ruler
- paper clips (48)
- plastic straws (8)
- pushpins (48, 12 each of a different color)
- scissors

Safety Cautions Caution students to be careful of the sharp tips of the pushpins. Account for all materials at the end of the lab.

Answers to Analysis

1. No, they are complementary. They differ from each other but pair up together.
2. The nucleotides on the first strand were placed randomly. The nucleotides on the second strand were complementary to those on the first strand.
3. The structure contains two complementary strands. Therefore, a dividing cell would have a copy of the DNA for each daughter cell.

Teaching Key Ideas

DNA's Code Because the sugar-phosphate "backbone" of the DNA molecule is always the same, the parts of the DNA molecule that are different, the nitrogen bases, must contain the genetic code.

Teach, *continued*

Teaching Key Ideas

Representation of DNA It is the sequence of the nucleotide bases that code for a gene, not the sugar-phosphate backbone. Therefore just the letters of the corresponding bases are shown. Have students practice base-pairing by matching letters to any series of base letters you write on the board.

READING TOOLBOX

Visual Literacy Have students look at **Figure 5** and determine which bases seem to pair. (A, *adenine* with T, and G, *guanine* with C, *cytosine*) Have students think of mnemonics to help them remember this order. (G looks like a good fit for C.)

ACADEMIC VOCABULARY

complementary being separate parts that improve or enhance each other

Complementary Sides **Figure 5** shows a simpler way to represent base-pairing. Paired bases are said to be complementary because they fit together like puzzle pieces. For example, if the sequence of nitrogen bases on one strand is TATGAGAGT, the sequence of nitrogen bases on the other strand must be ATACTCTCA. The pairing structure ensures that each strand of a DNA molecule contains the same information. However, the information on one strand is in reverse order from that on the other strand.

Discovering DNA's Structure

How were James Watson and Francis Crick able to determine the double-helical structure of DNA? **Watson and Crick used information from experiments by Chargaff, Wilkins, and Franklin to determine the three-dimensional structure of DNA.**

Observing Patterns: Chargaff's Observations In 1949, biochemist Erwin Chargaff made an interesting observation about DNA. His data showed that for each organism that he studied, the amount of adenine always equaled the amount of thymine (A = T). Similarly, the amount of guanine always equaled the amount of cytosine (G = C). **Figure 6** shows some of Chargaff's data. Watson and Crick used this information to determine how nucleotides are paired in DNA.

Using Technology: Photographs of DNA The significance of Chargaff's data became clear when scientists began using X rays to study the structures of molecules. In 1952, Rosalind Franklin, shown in **Figure 6,** and Maurice Wilkins developed high-quality X-ray diffraction images of strands of DNA. These photographs suggested that the DNA molecule resembled a tightly coiled helix and was composed of two chains of nucleotides.

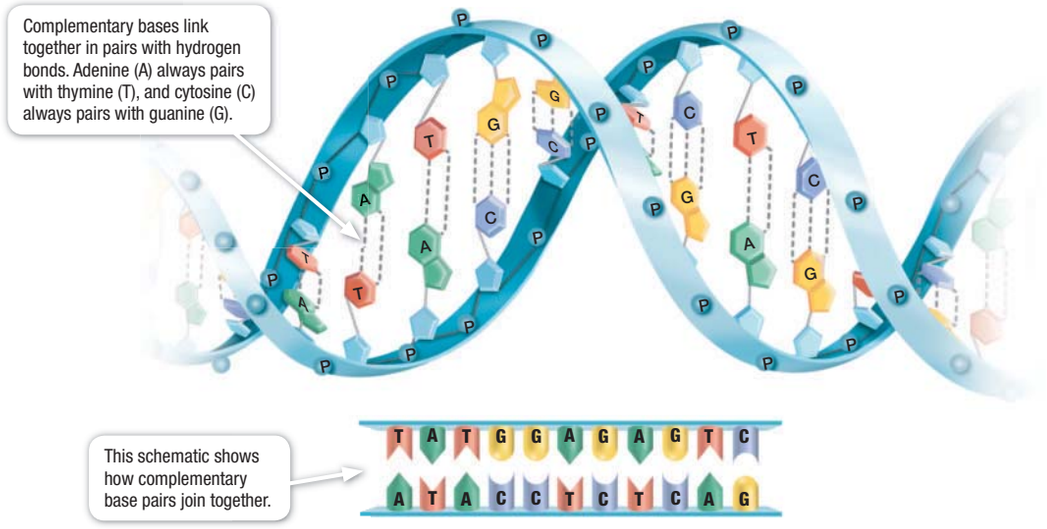


Figure 5 The diagram of DNA below the double helix simplifies the base pairing that occurs between DNA strands.

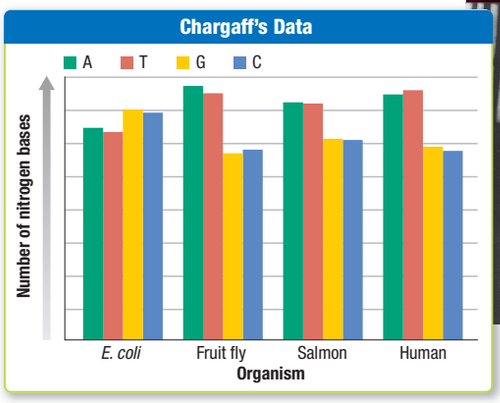
Why It Matters

Crediting Rosalind Franklin Watson and Crick are generally credited with determining the structure of DNA. However, Franklin's X-ray diffraction photograph was crucial to their discovery. Franklin would have received the Nobel Prize, along with Watson, Crick, and Wilkins, had she been alive when it was awarded.

Differentiated Instruction

Advanced Learners/GATE

Genetics in the News Have students research the history of the Nobel Prize. How many prizes have been awarded since 1962 for discoveries related to genetics?



Watson & Crick

Franklin

Figure 6 Chargaff's data and Franklin's X-ray diffraction studies were instrumental in the discovery of DNA's structure. Watson and Crick are shown with their tin and wire model of DNA.

Watson and Crick's Model of DNA To determine the three-dimensional structure of DNA, Watson and Crick set out to build a model of DNA. They knew that any model would have to take into account both Chargaff's data and the findings from Franklin's X-ray diffraction studies. In 1953, Watson and Crick used these findings, along with knowledge of chemical bonding, to create a complete three-dimensional model of DNA. By using paper models of the bases, Watson and Crick worked out the pairing structure of purines with pyrimidines. Then, they built a large model of a DNA double helix by using tin, wire, and other materials. Their model showed a "spiral staircase" in which two strands of nucleotides twisted around a central axis. **Figure 6** shows Watson and Crick with their model.

Nine years later, in 1962, the Nobel Prize was awarded to Watson, Crick, and Wilkins for their discovery. Rosalind Franklin died in 1958 and was not named in the award.

Reading Check ***How was X-ray diffraction used to model the structure of DNA?***

Section 1 **Review**

KEY IDEAS

1. **Identify** the substance that makes up genetic material.
2. **Name** the experiments that identified the role of DNA.
3. **Draw** the shape of a DNA molecule.
4. **Relate** the structure of DNA to the function of DNA as a carrier of information.
5. **Name** the studies that led to the discovery of DNA's structure.

CRITICAL THINKING

6. **Applying Information** If a DNA strand has the nucleotide sequence of CCGAGATTG, what is the nucleotide sequence of the complementary strand?
7. **Applying Information** What might Hershey and Chase have concluded if they had found ^{35}S instead of ^{32}P in bacterial cells? Explain your answer.

USING SCIENCE GRAPHICS

8. **Evaluating Graphics** Look at the graph of Chargaff's data in **Figure 6.** How do the amounts of adenine compare with the amounts of thymine across species? How do the amounts of cytosine and guanine compare? How did these data lead to the discovery of the base-pairing rules by Chargaff? How was this discovery used to determine DNA's structure?

Teaching Key Ideas

Watson and Crick's Model Stress that Watson and Crick built the three-dimensional model shown in **Figure 6.** Their model showed the chemical arrangement of the components of DNA. They published their findings in a historic one-page article in the journal *Nature*, in April of 1953.

Close

Formative Assessment

Base-pairing is very important to the structure of DNA, because it allows ____.

A. adenine to bond with guanine (Incorrect. Adenine bonds with thymine.)

B. pyrimidines to bond with each other (Incorrect. Pyrimidines cannot bond with each other.)

C. DNA to be copied (Correct! DNA's information is in the order of the bases.)

D. nucleotides to form (Incorrect. A nucleotide exists independent of base-pairing.)

Answers to Section Review

1. DNA is the primary substance that makes up genetic material.
2. The experiments of Griffith, Avery, Hershey, and Chase led to the conclusion that DNA is the primary carrier of genetic information in cells.
3. Drawings should show a spiral staircase composed of two parallel strands of linked subunits.
4. The information in DNA is contained in the order of bases. The base-pairing structure allows the information to be copied.
5. those of Chargaff, Franklin, and Wilkins
6. GGCTCTAAC.
7. They would have concluded that protein was the carrier of genetic information. Sulfur is found in proteins but not in DNA.
8. The amount of adenine is almost equal to the amount of thymine; the amount of guanine is almost equal to the amount of cytosine. This data revealed that nucleotides pair in a predictable manner.

Section 2

Section 2 Replication of DNA

Key Ideas	Key Terms	Why It Matters
How does DNA replicate, or make a copy of itself? What are the roles of proteins in DNA replication? How is DNA replication different in prokaryotes and eukaryotes?	DNA replication DNA helicase DNA polymerase	Understanding how DNA is copied has led to a better understanding of genetic diseases and cancer.

Focus

This section explains how DNA is copied, and the role DNA polymerase has in correcting copy errors. Replication in prokaryotes is compared to that in eukaryotes.

Bellringer

Use the Bellringer transparency to prepare students for this section.

Teach

Teaching Key Ideas

Ask students why it is important for the DNA in one cell to be like that of another. (so the new cell will have all the information it needs to function properly) LS Logical

READING TOOLBOX

Visual Literacy Ask students why the Y-shaped areas **Figure 7** are called *forks*. (the separation of a section of DNA is like a "fork" in the road) Ask students to paraphrase the three steps identified in DNA replication. LS Visual

When cells divide, each new cell contains an exact copy of the original cell's DNA. How is this possible?

DNA Replication

Remember that DNA is made of two strands of complementary base pairs. Adenine always pairs with thymine, and guanine always pairs with cytosine. If the strands of DNA are separated, as shown in **Figure 7,** each strand can serve as a pattern to make a new complementary strand. This separation allows two exact copies of DNA to be made from the original DNA molecule. Copying the DNA before cell division allows each new cell to have DNA identical to the original cell's.

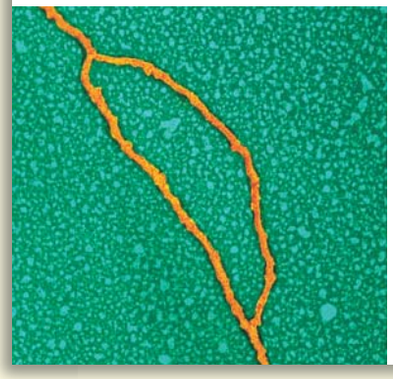
The process of making a copy of DNA is called **DNA replication.** **In DNA replication, the DNA molecule unwinds, and the two sides split. Then, new nucleotides are added to each side until two identical sequences result.** DNA replication occurs before a cell divides so that each cell has a complete copy of DNA. The basic steps of DNA replication are described below and are illustrated in **Figure 8** on the next page.

Step 1 Unwinding and Separating DNA Strands Before DNA replication can begin, the double helix unwinds. The two complementary strands of DNA separate from each other and form Y shapes. These Y-shaped areas are called *replication forks.* **Figure 7** shows two replication forks in a molecule of DNA.

Step 2 Adding Complementary Bases At the replication fork, new nucleotides are added to each side and new base pairs are formed according to the base-pairing rules. For example, if one of the original strands has thymine, then adenine will be paired with thymine as the new strand forms. Thus, the original two strands serve as a template for two new strands. As more nucleotides are added, two new double helixes begin to form. The process continues until the whole DNA sequence has been copied.

Step 3 Formation of Two Identical DNA Molecules This process of DNA replication produces two identical DNA molecules. Each double-stranded DNA helix is made of one new strand of DNA and one original strand of DNA. The nucleotide sequences in both of these DNA molecules are identical to each other and to the original DNA molecule.

Figure 7 When the two strands of the DNA helix separate, Y-shaped replication forks form.



Key Resources

Transparencies
C12 DNA Replication
C13 Replication Forks

Visual Concepts
DNA Replication
Snapshot of Replication
Replication Forks Increase the Speed of Replication

go.hrw.com
interact online
Keyword: HX8DNAF8

DNA Replication

1 Proteins called *helicases* separate the two original DNA strands.

2 Complementary nucleotides are added to each strand by DNA polymerases.

3 Two DNA molecules are formed that are identical to the original DNA molecule.

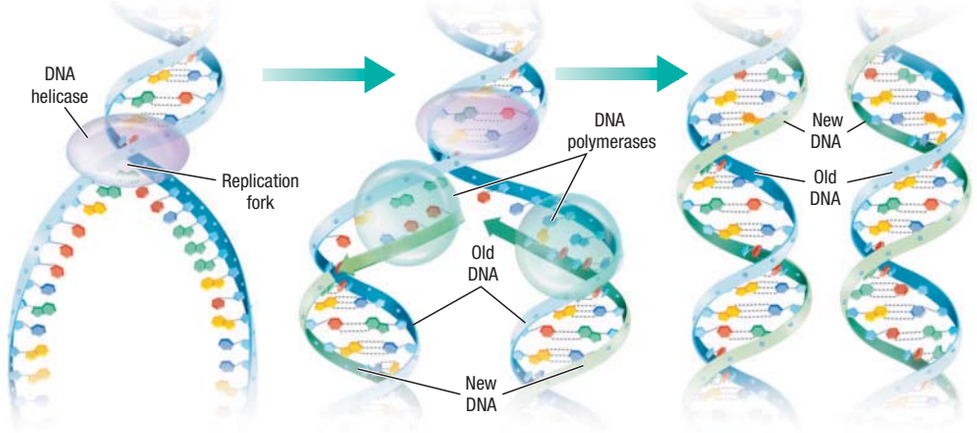


Figure 8 DNA replication results in two identical DNA strands.

Replication Proteins

During the replication of DNA, many proteins form a machinelike complex of moving parts. Each protein has a specific function.

DNA Helicase Proteins called **DNA helicases** unwind the DNA double helix during DNA replication. These proteins wedge themselves between the two strands of the double helix and break the hydrogen bonds between the base pairs. This process causes the helix to unwind and forms a replication fork, as **Figures 7** and **8** show. Additional proteins keep the two strands separated so that replication can occur.

DNA Polymerase Proteins called **DNA polymerases** catalyze the formation of the DNA molecule. At the replication fork, DNA polymerases move along each strand. The polymerases add nucleotides that pair with each base to form two new double helixes. After all of the DNA has been copied, the polymerases are released.

DNA polymerases also have a "proofreading" function. During DNA replication, errors sometimes occur, and the wrong nucleotide is added to the new strand. DNA polymerases cannot add another nucleotide unless the previous nucleotide is correctly paired with its complementary base. If a mismatch occurs, the DNA polymerase can backtrack, remove the incorrect nucleotide, and replace it with the correct one. Proofreading reduces the replication errors to about one per 1 billion nucleotides.

Reading Check ***Why is proofreading critical during replication?***

DNA replication the process of making a copy of DNA

DNA helicase (HEEL uh KAYS) an enzyme that unwinds the DNA double helix during DNA replication

DNA polymerase (puh LIM uhr AYS) an enzyme that catalyzes the formation of the DNA molecule

go.hrw.com
interact online

Students can interact with "DNA Replication" by going to go.hrw.com and typing the keycode HX8DNAF8.

Teaching Key Ideas

Role of Enzymes Before DNA can make copies of itself, it must "unzip," by breaking the hydrogen bonds that hold the nitrogen bases together. Ask students what kinds of molecules can break bonds in a chemical reaction. (enzymes) Then, ask them what kind of molecules assist in the bonding process. (enzymes) Close by reviewing the names of the enzymes involved in both processes. (DNA helicases and DNA polymerases) LS **Verbal**

READING TOOLBOX

Visual Literacy Ask students to describe how the original strand of DNA is distinguished from the new molecule, in Step 3 of **Figure 8.** (They are different colors.) Call attention to the fact that each half of the original DNA molecule serves as a template for the new molecule. This *semi-conservative* model is distinguished from a *conservative* model, in which the parent molecule is *conserved*, and the new molecule is formed from scratch. LS **Visual**

Differentiated Instruction

Basic Learners

Replication Model Use two pieces of red yarn to represent the DNA. Use colored paperclips, joined in the center, to represent the nitrogen bases holding the two strands together. Describe the role of DNA helicase as you separate the two strands by unhooking the paperclips. Take two blue pieces of yarn and add paperclips in a sequence that pairs them to each side of the red strands. Join the new strands to each half of the original strand. *One* original molecule is serving as a template for *two* new molecules. LS **Visual**

Teach, *continued*

READING TOOLBOX

Word Parts **helicase** an enzyme that acts on a spiral structure; **polymerase** an enzyme that acts on a polymer

READING TOOLBOX

Visual Literacy Ask students to interpret **Figure 9**. (From a "circle" of DNA, replication begins at one point, inside the circular piece of DNA and proceeds in opposite directions. With linear eukaryotic DNA, replication begins at many points, forming many replication forks. As replication continues, the replication bubbles grow until replication is completed.) Have students compare the process of replication, on the eukaryotic DNA to the prokaryotic DNA. Ask how both processes are alike. (Both processes proceed in opposite directions.) LS **Visual, Kinesthetic**

Answers to Caption Questions

Figure 9: Replication occurs at multiple replication forks so that the single, long strand of DNA is replicated more rapidly.

READING TOOLBOX

Word Parts In your own words, write a definition of *helicase* and *polymerase*, the names of the enzymes involved in DNA replication, based on the meanings of each term's word parts.

ACADEMIC VOCABULARY

distinct separate; not the same

Prokaryotic and Eukaryotic Replication

Both prokaryotes and eukaryotes replicate their DNA to reproduce and grow. Recall that the packaged DNA in a cell is called a *chromosome*. All cells have chromosomes, but eukaryotes and prokaryotes replicate their chromosomes differently. **› In prokaryotic cells, replication starts at a single site. In eukaryotic cells, replication starts at many sites along the chromosome.**

Prokaryotic DNA Replication Prokaryotic cells usually have a single DNA molecule, or chromosome. Prokaryotic chromosomes are a closed loop, may contain protein, and are attached to the inner cell membrane. Replication begins at one place along the DNA loop. Two replication forks begin at that single point, which is known as the origin of replication. Replication occurs in opposite directions until the replication forks meet on the opposite side of the DNA loop and the entire molecule has been copied. **Figure 9** shows prokaryotic DNA replication.

Eukaryotic DNA Replication While prokaryotes have a single chromosome, eukaryotic cells often have several chromosomes. Eukaryotic chromosomes differ from the simple, looped chromosomes found in prokaryotic cells. Eukaryotic chromosomes are linear, and they contain both DNA and protein. Recall that the long molecules of DNA are tightly wound around proteins called *histones* and are packaged into thick chromosome fibers.

By starting replication at many sites along the chromosome, eukaryotic cells can replicate their DNA faster than prokaryotes can. As in prokaryotic replication, two distinct replication forks form at each start site, and replication occurs in opposite directions. This process forms replication "bubbles" along the DNA molecule. The replication bubbles continue to get larger as more of the DNA is copied. As **Figure 9** shows, they eventually meet to form two identical, linear DNA molecules. Because multiple replication forks are working at the same time, an entire human chromosome can be replicated in about eight hours. Then, the cell will be ready to divide.

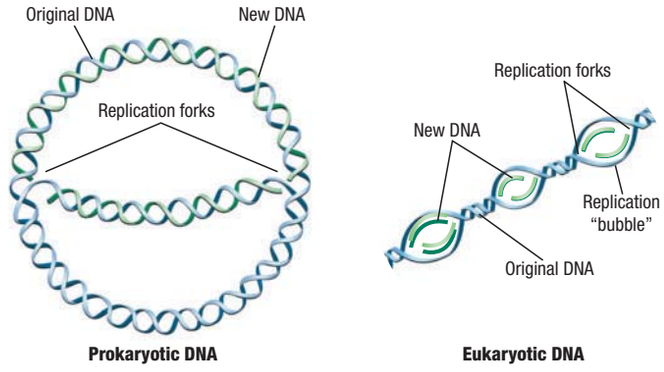


Figure 9 Prokaryotic and eukaryotic DNA have different numbers of replication forks. **› Why does replication in eukaryotes involve more replication forks?**

Differentiated Instruction

Special Education Students

Replication Fork Model To help visually impaired and developmentally delayed students understand the work of replication forks, try the following model. Obtain two perfectly matched, separating, fabric zippers for each student. Tag the second zipper in some way so that visually impaired students can tell the difference between the two zippers. You can use different colors for developmentally delayed students. Give students one zipper and let them manipulate it. Ask them what part of the zipper–DNA model represents helicase? (the zipper mechanism) After they separate the first zipper, give them the second zipper that is already separated into the two strands. Have them create two new zippers by zipping the "replication" strands. Students should have two matching zippers, each made of the parent strand and the replication strand. Ask them what happens if the replication strand is not a complementary match. (The zipper won't close.) LS **Visual**

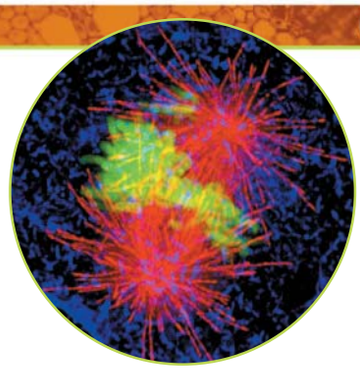
Data

QuickLab

15 min

DNA Replication Rate

Cancer is a disease caused by cells that divide uncontrollably. Scientists studying drugs that prevent cancer often measure the effectiveness of a drug by its effect on DNA replication. During normal DNA replication, nucleotides are added at a rate of about 50 nucleotides per second in mammals and 500 nucleotides per second in bacteria.



Analysis

1. **Calculate** the time it would take a bacterium to add 4,000 nucleotides to one DNA strand undergoing replication.
2. **Calculate** the time it would take a mammalian cell to add 4,000 nucleotides to one DNA strand undergoing replication.
3. CRITICAL THINKING **Predicting Outcomes** How would the total time needed to add the 4,000 nucleotides be affected if a drug that inhibits DNA polymerases were present? Explain your answer.

Size of Eukaryotic DNA The smallest eukaryotic chromosomes are often 10 times the size of a prokaryotic chromosome. If a scientist took all of the DNA in a single human cell and laid the DNA in one line (that is, laid the DNA from all 46 chromosomes end to end), the line would be 2 m long. In contrast, if the scientist laid out the DNA from one bacterial chromosome, the line would be only about 0.25 cm long. In fact, the length of eukaryotic chromosomes is so long that replication of a typical human chromosome would take 33 days if there were only one origin of replication.

Each human chromosome is replicated in about 100 sections that are 100,000 nucleotides long, each section with its own starting point. With multiple replication forks working in concert, an entire human chromosome can be replicated in about 8 hours.

SCILINKS
www.scilinks.org
Topic: DNA Replication
Code: HX80420

› **Reading Check** *How is a "replication bubble" formed?*

Section 2 Review

KEY IDEAS

1. **Describe** the steps of DNA replication.
2. **Compare** the roles of DNA helicases and DNA polymerases.
3. **Compare** the process of DNA replication in prokaryotes and in eukaryotes.

CRITICAL THINKING

4. **Inferring Relationships** What is the relationship between DNA polymerases and mutations in DNA?
5. **Relating Concepts** Cancer is a disease caused by cells that divide uncontrollably. Scientists are researching drugs that inhibit DNA polymerase as potential anti-cancer drugs. Why would these drugs be useful against cancer?

ALTERNATIVE ASSESSMENT

6. **Replication Model** Conduct research on the shapes of prokaryotic and eukaryotic chromosomes. Draw a model of each type of chromosome. How does the structure of chromosomes in prokaryotic cells and eukaryotic cells affect the DNA replication processes in a cell?

Answers to Section Review

1. The DNA molecule unwinds and separates. Nucleotides are matched to each side, creating two identical sequences and forming two new molecules.
2. DNA helicase breaks the bonds between the nitrogen bases, "unzipping" the molecule; DNA polymerase adds nucleotides in a strand to the original half, and "proofreads" the added nucleotides.
3. Prokaryotic replication starts at a single site. Eukaryotic replication starts at several sites. Both processes proceed in opposite directions.
4. DNA polymerase prevents mutations by eliminating incorrectly-placed nucleotides during replication.
5. Because DNA polymerase joins new nucleotides to make DNA before cell division, its absence may prevent uncontrolled cell division.
6. Eukaryotes have more chromosomes and longer DNA. Thus, replication would take too long if the eukaryotic cell followed the same process as the smaller prokaryotic cell.

QuickLab

Teacher's Notes Remind students that rates are ratios that compare different quantities, such as miles per hour.

Answers to Analysis

1. 8 seconds
2. 80 seconds
3. The total time would increase. A drug that inhibits DNA polymerase action would slow down the total time needed to add nucleotides.

Teaching Key Ideas

Explanation for Differences in Replication Call attention to the fact that multiple replication forks are necessary in eukaryotes because of the amount of DNA that needs to be replicated. There is efficiency in processing several at once. LS Logical

Close

Formative Assessment

Why does a eukaryotic cell need a replication process that's different from that for a prokaryotic cell?

A. The prokaryotic DNA is longer and needs several replication sites to increase the rate. (Incorrect. Eukaryotic DNA is longer.)
B. The eukaryotic DNA is longer and needs several replication sites to increase the replication rate. (Correct!)
C. The bacterial DNA is longer and needs several replication sites to increase the rate. (Incorrect! Bacteria are prokaryotes, and have shorter DNA.)
D. Prokaryotes have more chromosomes. (Incorrect. Eukaryotes have more chromosomes and longer DNA.)

Section 3 RNA and Gene Expression

Key Ideas	Key Terms	Why It Matters
What is the process of gene expression? What role does RNA play in gene expression? What happens during transcription? How do codons determine the sequence of amino acids that results after translation? What are the major steps of translation? Do traits result from the expression of a single gene?	RNA gene expression transcription translation codon	Traits, such as eye color, are determined by proteins that are built according to instructions coded in DNA.

Focus

This section discusses the role of DNA in directing the formation of proteins. RNA is introduced as the nucleic acid that assembles amino acids to form a protein. Students learn how a three-letter sequence on DNA is transcribed onto mRNA. This three-letter codon dictates the sequence of amino acids on the ribosome using tRNA as a "taxi service" to deliver the specific amino acid specified by a particular codon.

Bellringer

Use the Bellringer transparency to prepare students for this section.

Teach

Teaching Key Ideas

Clarifying Terms Ask students to define the term *gene*. (unit of hereditary information on a section of DNA) Stress that genes contain the code for an amino acid sequence. Ask where amino acid assembly takes place. (ribosomes) Ask why the *entire* DNA molecule is not copied. (there is too much unneeded information) DNA is a large molecule that cannot exit the nucleus. Ask students how this problem is solved for the cell. (Directions are given to a carrier molecule. This molecule is RNA.) LS Verbal

Proteins perform most of the functions of cells. DNA provides the original "recipe," or information, from which proteins are made in the cell. However, DNA does not directly make proteins. A second type of nucleic acid, ribonucleic acid, or **RNA,** is essential in taking the genetic information from DNA and building proteins.

An Overview of Gene Expression

Gene expression is the manifestation of genes into specific traits.

Gene expression produces proteins by transcription and translation. This process takes place in two stages, both of which involve RNA. **Figure 10** illustrates the parts of the cell that play a role in gene expression.

Transcription: DNA to RNA The first stage of gene expression, which is making RNA from the information in DNA, is called **transcription.** You can think of transcription as copying (transcribing) notes from the board (DNA) to a notebook (RNA).

RNA ribonucleic acid, a natural polymer that is present in all living cells and that plays a role in protein synthesis

gene expression the manifestation of the genetic material of an organism in the form of specific traits

transcription the process of forming a nucleic acid by using another molecule as a template

translation the portion of protein synthesis that takes place at ribosomes and that uses the codons in mRNA molecules to specify the sequence of amino acids in polypeptide chains

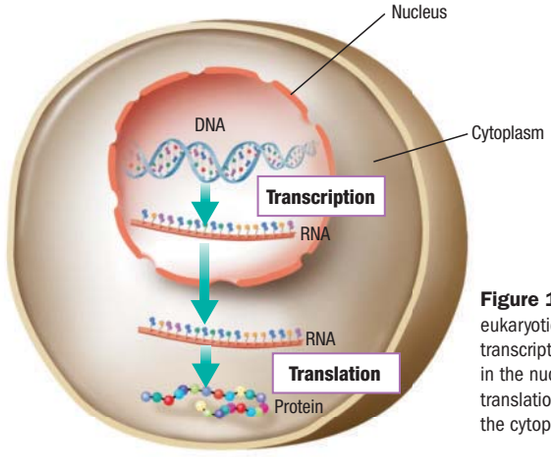


Figure 10 In eukaryotic cells, gene transcription occurs in the nucleus and translation occurs in the cytoplasm.

Key Resources

Transparencies
C15 Transcription
C16 Codons in mRNA
C17 Translation: Assembling Proteins

Visual Concepts
Ribonucleic Acid
Comparing DNA and RNA
Gene Expression
Transcription
Promoter
Codons in mRNA
Genetic Code
tRNA and Anticodon
Translation
Snapshot of Translation
Ribosomes

Translation: RNA to Proteins The second stage of gene expression, called **translation,** uses the information in RNA to make a specific protein. Translation is similar to translating a sentence in one language (RNA, the nucleic acid "language") to another language (protein, the amino acid "language").

RNA: A Major Player

All of the steps in gene expression involve RNA. Several types of RNA are used in transcription and translation. **› In cells, three types of RNA complement DNA and translate the genetic code into proteins.** But what exactly is RNA, and how does it compare to DNA?

RNA Versus DNA Like DNA, RNA is a nucleic acid—a molecule made of nucleotide subunits linked together. Like DNA, RNA has four bases and carries information in the same way that DNA does.

RNA differs from DNA in three ways. First, RNA usually is composed of one strand of nucleotides rather than two strands. The structural difference between the two nucleotides is shown in **Figure 11.** Second, RNA nucleotides contain the five-carbon sugar *ribose* rather than the sugar deoxyribose. Ribose contains one more oxygen atom than deoxyribose does. And third, RNA nucleotides have a nitrogenous base called *uracil* (U) instead of the base thymine (T). Although no thymine (T) bases are found in RNA, the other bases (A, G, and C) are identical to the bases found in DNA. In place of thymine, uracil (U) is complementary to adenine (A) whenever RNA pairs with another nucleic acid.

Types of RNA There are several types of RNA. Three main types of RNA play a role in gene expression. These types are messenger RNA, transfer RNA, and ribosomal RNA.

Messenger RNA When DNA is transcribed into RNA, *messenger RNA* (mRNA) is the type of RNA that is produced. mRNA is complementary to the DNA sequence of a gene. The mRNA carries instructions for making a protein from a gene and delivers them to the site of translation.

Transfer RNA During translation, *transfer RNA* (tRNA) "reads" the mRNA sequence. Then, tRNA translates the mRNA sequence into a specific sequence of protein subunits, or amino acids. tRNA molecules have amino acids attached to them, and the tRNA molecules act as decoders by matching the mRNA sequence and placing the amino acids on growing protein chains.

Ribosomal RNA Protein production occurs on cellular structures called *ribosomes*. Ribosomes are made up of about 80 protein molecules (ribosomal proteins) and several large RNA molecules. The RNA that is found in ribosomes is called *ribosomal RNA* (rRNA). A cell's cytoplasm contains thousands of ribosomes. In eukaryotic cells, ribosomes are attached to the endoplasmic reticulum (ER), which transports proteins as the proteins are produced.

› **Reading Check** ***What are the structural differences between RNA and DNA?***

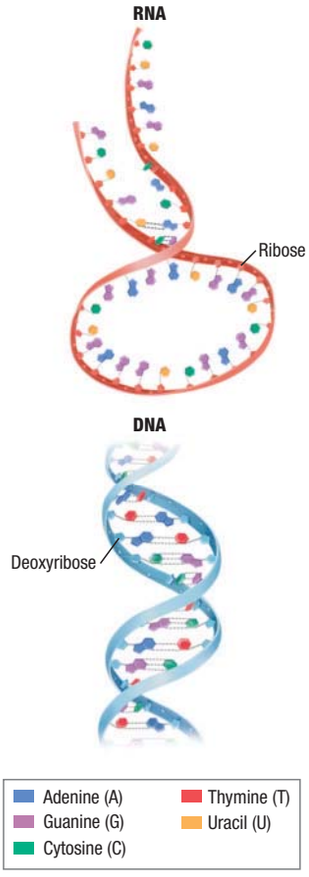


Figure 11 Both RNA (top) and DNA (bottom) are nucleic acids.

Teaching Key Ideas

Transcription versus Translation To help students remember *transcription* show the "script" part of the word and equate this process with *writing*. Stress that the code found on DNA is *written* into another language, that of RNA. Compare *translation* to making this new language meaningful to the cell by forming proteins. LS Verbal

READING TOOLBOX

Word Parts Draw the structure of deoxyribose and ribose on the board. Ask students to compare these sugars. (They are identical except for one less oxygen on DNA.) Ask students how this exception is reflected in the names of each sugar. (*Deoxy*ribose is *deoxy*genated.) LS Visual/Verbal

Teaching Key Ideas

Comparing DNA and RNA Draw four ribose sugars on the board, representing each as a pentagram. Add a circle (to represent a phosphate) to each pentagram circle. Show each of the nitrogen bases as a letter attached to the ribose. Ask students to identify the difference between DNA nucleotide bases and those of RNA. (Uracil has been substituted for thymine.) Stress that these nucleotides and DNA nucleotides are found in the nucleus. Ask students how many different kinds of nucleotides are in the nucleus. (eight) LS Visual

Differentiated Instruction

Alternative Assessment

Replication Have students write two sentences to describe each of the three steps summarizing DNA replication shown in **Figure 8.**

English Learners

Genes, Proteins, and DNA Ask students to clarify the difference between a gene, a protein, and DNA. (A gene is part of DNA. A polypeptide is made from the directions in a section of DNA.) Refer students to **Figure 10** and ask them to identify the two main processes of gene expression. (transcription and translation) LS Visual

Teach, *continued*

go.hrw.com
interact online

Students can interact with "Transcription" by going to go.hrw.com and typing in the keyword HX8DNAF12.

READING TOOLBOX

Three-Panel Flip Chart Students' charts should include the following information:
mRNA produced by transcription, complementary to the gene DNA; delivers code for protein synthesis to the ribosome
tRNA reads mRNA during translation at the ribosome; codes for a specific amino acid sequence to create proteins
rRNA a component of the ribosome

Teaching Key Ideas

Transcription Process Tell students that the section of DNA that is transcribed is called the "sense" strand. The sense strand is only one-half of the DNA molecule. RNA polymerase recognizes the "start" site—the promoter region on DNA. RNA polymerase then "reads" the sequence of DNA bases and then "writes" it into mRNA language, linking complementary RNA nucleotides until it reaches a "stop" signal. The rate of transcription is about 60 nucleotides per second.

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Transcription

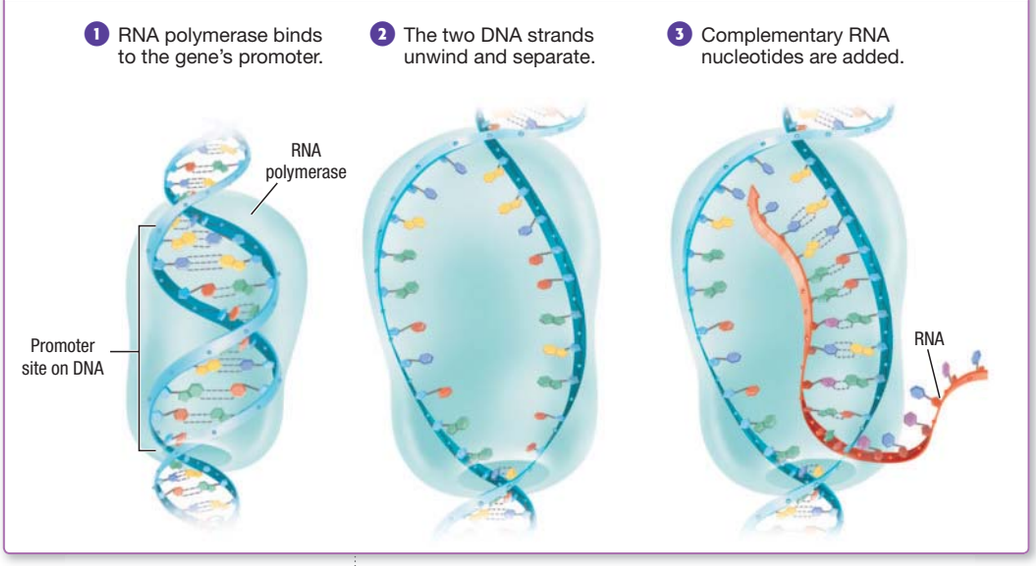

Figure 12 Transcription is the process in which mRNA is made to complement the DNA of a gene.

Transcription: Reading the Gene

During transcription, the information in a specific region of DNA (a gene) is transcribed, or copied, into mRNA. Transcription is carried out by a protein called *RNA polymerase*. The steps of transcription are described below and are shown in **Figure 12.**

Step 1 Transcription begins when RNA polymerase binds to the specific DNA sequence in the gene that is called the *promoter*. The promoter site is the "start" location.

Step 2 RNA polymerase then unwinds and separates the two strands of the double helix to expose the DNA bases on each strand.

Step 3 RNA polymerase adds and links complementary RNA bases as it "reads" the gene. RNA polymerase moves along the bases on the DNA strand in much the same way that a train moves along a track. Transcription follows the base-pairing rules for DNA replication except that in RNA, uracil—rather than thymine—pairs with adenine. As RNA polymerase moves down the DNA strand, a single strand of mRNA grows. Behind the moving RNA polymerase, the two strands of DNA close up and re-form the double helix.

The RNA polymerase eventually reaches a "stop" location in the DNA. This stop signal is a sequence of bases that marks the end of each gene in eukaryotes or the end of a set of genes in prokaryotes. The result is a single strand of mRNA.

Reading Check *What is the role of a promoter?*

READING TOOLBOX

Three-Panel Flip Chart Make a three-panel flip chart to help you compare the roles of the three types of RNA used in gene expression.

Differentiated Instruction

Basic Learners

Recognizing the Code Draw a figure similar to Step 2 of **Figure 12.** Randomly assign base letters to the right half (sense strand) of DNA. Make sure they are a number that is a multiple of three. Label the promoter region, and the stop location. Have student volunteers come to the board to add letters for RNA nucleotides. The letters added should be connected. Label the newly-transcribed single strand as mRNA. Have students design their own sequences using the model on the board. LS Visual

English Learners

RNA Pairing Rules Reinforce that adenine, A, on a DNA strand pairs with uracil, U, instead of thymine, T. RNA never includes thymine. Have students recite base pairings to help reinforce this change. LS Verbal

Transcription Versus Replication Like DNA replication, transcription uses DNA as a template for making a new molecule. In transcription, a new molecule of RNA is made from the DNA. However, in DNA replication, a new molecule of DNA is made from the DNA. Also, in DNA replication, both strands of DNA serve as templates. In contrast, during transcription only part of one of the two strands of DNA (a gene) serves as a template for the new RNA.

The Genetic Code: Three-Letter "Words"

A gene can be thought of as a "sentence" of "words" that is first transcribed and then translated into a functional protein. Once a section of a gene is transcribed into mRNA, the words can be carried from the nucleus to ribosomes in the cytoplasm. There, the words are translated to make proteins.

Codons of mRNA Each of the words in mRNA is made up of three adjacent nucleotide bases. Each three-nucleotide sequence is called a **codon.** Each codon is matched to 1 of 20 amino acids or acts as a start or stop signal for the translation stage. **Figure 13** shows this matching system for each of the possible 64 mRNA codons. For example, the codon GCU specifies the amino acid alanine. Notice that each codon specifies only one amino acid but that several amino acids have more than one codon. This system of matching codons and amino acids is called the *genetic code.* **› The genetic code is based on codons that each represent a specific amino acid.**

SCILINKS
www.scilinks.org
Topic: Genetic Code
Code: HX80648

codon in DNA and mRNA, a three-nucleotide sequence that encodes an amino acid or signifies a start signal or a stop signal

Figure 13 The amino acid coded for by a specific mRNA codon can be determined by following the three steps below. **› What amino acid does the codon GAA code for?**

1 Find the first base of the mRNA codon in this column of the table.

2 Follow that row to the column that matches the second base of the codon.

3 Move up or down in that box until you match the third base of the codon with this column of the chart.

Codons in mRNA

First base	Second base U	Second base C	Second base A	Second base G	Third base
U	UUU, UUC: Phenylalanine UUA, UUG: Leucine	UCU, UCC, UCA, UCG: Serine	UAU, UAC: Tyrosine UAA, UAG: Stop	UGU, UGC: Cysteine UGA–Stop UGG–Tryptophan	U C A G
C	CUU, CUC, CUA, CUG: Leucine	CCU, CCC, CCA, CCG: Proline	CAU, CAC: Histidine CAA, CAG: Glutamine	CGU, CGC, CGA, CGG: Arginine	U C A G
A	AUU, AUC, AUA: Isoleucine AUG–Start	ACU, ACC, ACA, ACG: Threonine	AAU, AAC: Asparagine AAA, AAG: Lysine	AGU, AGC: Serine AGA, AGG: Arginine	U C A G
G	GUU, GUC, GUA, GUG: Valine	GCU, GCC, GCA, GCG: Alanine	GAU, GAC: Aspartic acid GAA, GAG: Glutamic acid	GGU, GGC, GGA, GGG: Glycine	U C A G

Why It Matters

Redundant Codons Call students' attention to several amino acids that have more than one codon. (leucine, serine, glycine, and so on.) In each case, ask which of the three bases in the codon is different. (the last one) Ask what advantage this might have. (A mistake in the *last* letter of the codon would still specify the same amino acid.) Suggest that these amino acids might be more crucial to the growth and survival of an organism. LS Logical

Teaching Key Ideas

Triplet Combination Have students recall the number of amino acids (20), and have them think back to the Inquiry Lab that involved paperclips. Two color combinations could provide only sixteen choices. LS Logical

Math Skills

Counting Methods When four bases are joined in three combinations (codons), there are sixty-four possible choices. Represent this as 4^3 (four bases and three combinations). LS Logical

READING TOOLBOX

Visual Literacy Familiarize students with codons and the amino acids they specify. Use the transparency, call out the three-letter sequence for several codons, and have students name the amino acid. Next, show the students how to read the chart, if *given* a codon. (Follow cues 1–3.) Ask students whether *all* codons specify an amino acid. (No, there are three stop codons: UAA, UAG, UGU. Therefore, only 61 codons actually code for an amino acid.) LS Visual

Answers to Caption Questions

Figure 13: The codon GAA codes for glutamic acid.

Teaching Key Ideas

"Taxi" RNA In the last step of protein synthesis, the language of mRNA codons is translated into the language of proteins (amino acid sequences). Transfer RNA (tRNA) acts as a "taxi service," bringing the specific amino acid to the ribosome for assembly. An anticodon sequence, matching the mRNA codon, makes this specificity possible.

READING TOOLBOX

Visual Literacy Use the codon sequence from **Figure 14** and write this sequence on a long strip(s) of paper. Post these on the board and mark off every three bases. Pass out prepared tRNA paper molecules with a circle on top, and call on individual students to name the amino acid and write its name on the circle. (Use **Figure 13.**) Emphasize the role of the ribosome in serving as a "workbench" that allows two amino acids to become closely positioned, so that peptide bonds can form between them. (Step 2) LS Visual

Translation

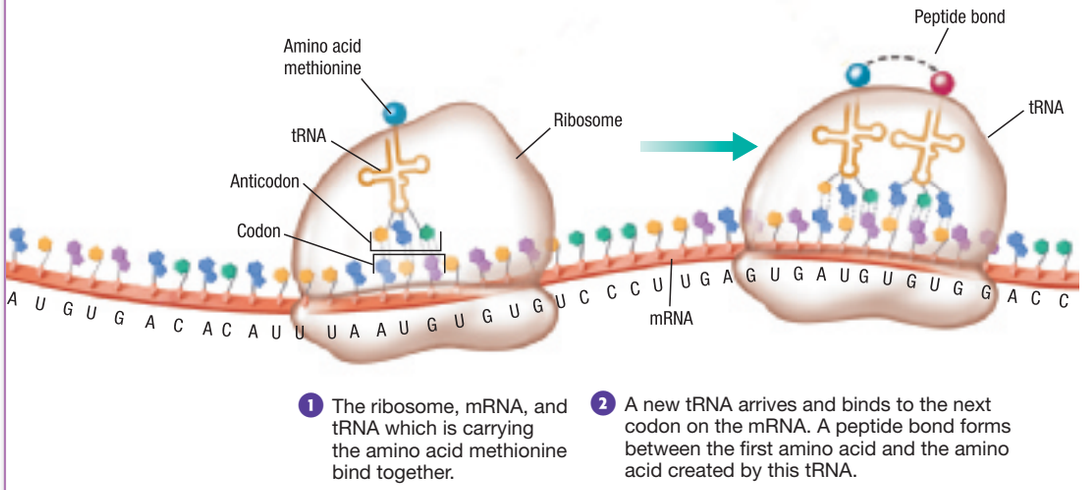

Figure 14 During translation, amino acids are assembled from information encoded in mRNA. As the mRNA codons move through the ribosome, tRNAs add specific amino acids to the growing polypeptide chain. This process continues until a stop codon is reached and the newly made protein is released.

Translation: RNA to Proteins

Translation is the process of converting the "language" of RNA (nucleotide sequences) into the "language" of proteins (amino acid sequences). **Translation occurs in a sequence of steps, involves three kinds of RNA, and results in a complete *polypeptide*.** In the cytoplasm, ribosomes are formed as tRNA, rRNA, and mRNA interact to assemble amino acid sequences that are based on the genetic code. The process of translation is summarized below and in **Figure 14.**

Step 1 Each tRNA is folded into a compact shape, as **Figure 15** shows. An amino acid is added to one end of each tRNA. The other end of the tRNA has an anticodon. An *anticodon* is a three-nucleotide sequence that is complementary to an mRNA codon. Each tRNA molecule carries the amino acid that corresponds with the tRNA's anticodon. After leaving the nucleus, the mRNA joins with a ribosome and tRNA. The mRNA start codon, AUG, signals the beginning of a protein chain. A tRNA molecule carrying methionine at one end and the anticodon, UAC, at the other end binds to the start codon.

Step 2 A tRNA molecule that has the correct anticodon and amino acid binds to the second codon on the mRNA. A peptide bond forms between the two amino acids, and the first tRNA is released from the ribosome. The tRNA leaves its amino acid behind.

MISCONCEPTION ALERT

Translation Make sure that students use the mRNA codons, not tRNA anticodons, for translation. Recall that DNA's triplet code is given to the RNA "messenger," mRNA. Its codons dictate the amino acids.

Why It Matters

Antibiotic Function The prokaryotic ribosome is smaller than the eukaryotic ribosome. Its protein and RNA content is also different. These differences allow selective antibiotics, such as tetracycline, to bind to prokaryotic ribosomes. This bonding interferes with protein synthesis, which kills the disease-causing bacteria. Humans can safely take antibiotics because the ribosomes are different and will not be affected by the antibiotic.

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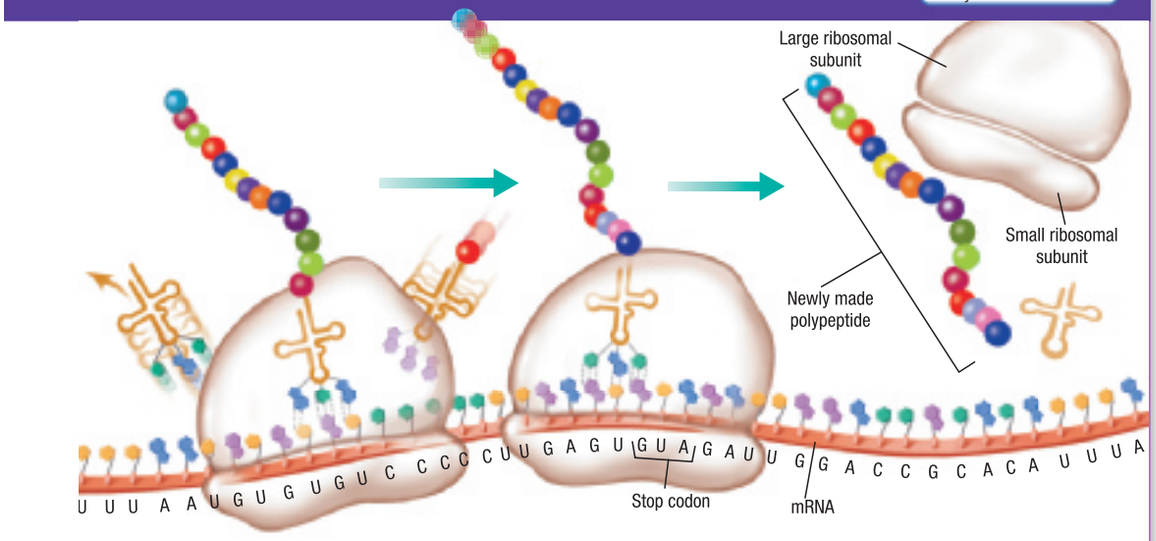


3 The first tRNA detaches and leaves its amino acid. With each new tRNA, the amino acid chain grows.

4 The process ends when a stop codon is reached.

5 The amino acid chain is released, and the ribosome complex falls apart.

Step 3 The ribosome moves one codon down the mRNA. Because the anticodon remains attached to the codon, the tRNA molecule and the mRNA molecule move as a unit, which leaves the next mRNA codon open and ready to receive the next tRNA and its amino acid. The amino acid chain continues to grow as each new amino acid binds to the chain and the previous tRNA is released.

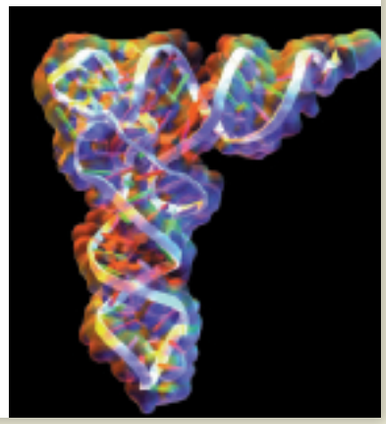
Step 4 This process is repeated until a stop codon is reached. A *stop codon* is one of three codons: UAG, UAA, or UGA. No tRNAs have anticodons for these stop codons, so protein production stops.

Step 5 The newly made polypeptide falls off the ribosome. The ribosome complex falls apart. The last tRNA leaves the ribosome, and the ribosome moves away from the mRNA. The ribosome is then free to begin translation again on the same mRNA or on another mRNA.

Repeating Translation Like replication, translation needs to happen quickly and often. As a segment of mRNA moves through a ribosome, another ribosome can form on the AUG codon on the same mRNA segment and can begin a new translation process. Thus, several ribosomes can translate the same mRNA at the same time, which allows many copies of the same protein to be made rapidly from a single mRNA molecule.

› **Reading Check** *How do codons and anticodons differ?*

Figure 15 tRNA folds into this shape such that an anticodon is on one end and a binding site for amino acids is on the other end.



Differentiated Instruction

Alternative Assessment

Translation Once students have completed the Translation Activity on this page and a review of **Figure 14,** have them close their books and write a summary of translation. LS Visual

Why It Matters

Polyribosomes A single ribosome can make an average-sized polypeptide in less than a minute. However, a single mRNA is often used to make many polypeptides by having several ribosomes trail along the mRNA, one after another, making the same polypeptide. These clusters, seen with the electron microscope, are called *polyribosomes.*

go.hrw.com
interact online

Students can interact with "Translation" by going to go.hrw.com and typing in the keyword HX8DNAF14.

READING TOOLBOX

Visual Literacy Stress that the ribosome in **Figure 14** moves down mRNA to the next codon. Note that once a newly delivered amino acid is bonded to the exiting polypeptide, the chain remains attached to the tRNA that delivered the last amino acid, and the tRNA "taxi" that previously held the growing chain is released. LS Visual

Teaching Key Ideas

Translation Activity To demonstrate the process of translation, make a paper molecule to resemble a ribosome. Position the ribosome *under* the strip of paper on the board, so that it is under two codons. Have students bring up their tRNAs and corresponding amino acids, attaching the amino acids with a piece of tape. Note: When the ribosome moves to the next codon (to the right), the tRNA with the growing polypeptide will change position, moving to the left. This leaves an open space for the new tRNA and its amino acid. LS Visual, Kinesthetic

QuickLab

Teacher's Notes Use **Figure 14** to review translation. Make sure students understand the terms codon and anticodon.

Answers to Analysis

1. serine–arginine–glutamic acid–phenylalanine–serine
2. AGA, GCA, CUU, AAA, AGG
3. AGAGCACTTAAAAGG
4. TCTCGTGAATTTTCC

Teaching Key Ideas

It's All There While the genetic code is specific and straightforward, the expression of genes is complex. There are several factors that influence gene expression. Stress that all of the DNA in a particular cell is not expressed. For example, genes coding for the formation of hemoglobin will not be expressed in a skin cell. Genes coding for the formation of a liver enzyme will not be expressed in a neuron. Remind students that *every cell contains all of the DNA for that organism.*

Close

Formative Assessment

RNA polymerase splits DNA as part of the _____ process.

A. translation (Incorrect. There is no splitting of DNA in translation.)
B. transcription (Correct! RNA polymerase splits the strand in the second step of translation.)
C. replication (Incorrect. DNA splitting in replication does not involve RNA enzymes.)
D. base-pairing (Splitting DNA does not involve base-pairing.)

Data

QuickLab

15 min

Genetic Code of Keratin

Keratin is one of the proteins in hair. The gene for keratin is transcribed and translated by certain skin cells. The sequence below is part of the mRNA molecule that is transcribed from the gene for keratin.

Analysis

1. **Determine** the sequence of amino acids that will result from the translation of the segment of mRNA above. Use the genetic code in **Figure 13.**
2. **Determine** the anticodon of each tRNA molecule that will bind to this mRNA segment.
3. CRITICAL THINKING **Recognizing Patterns** Determine the sequence of nucleotides in the segment of DNA from which this mRNA strand was transcribed.
4. CRITICAL THINKING **Recognizing Patterns** Determine the sequence of nucleotides in the segment of DNA that is complementary to the DNA segment that is described in item 3.

Complexities of Gene Expression

The relationship between genes and their effects is complex. Despite the neatness of the genetic code, every gene cannot be simply linked to a single outcome. Some genes are expressed only at certain times or under specific conditions. Some traits result from the expression of multiple genes. Variations, mistakes, feedback, and other complex interactions can occur at each of the steps in replication and expression. The final outcome of gene expression is affected by the environment of the cells, the presence of other cells, and the timing of gene expression.

Overall, knowledge of the basic process of gene expression has allowed scientists to better understand the workings of all organisms. The next chapters delve into the exciting results of applying this knowledge.

Section 3 Review

KEY IDEAS

1. **Describe** gene expression.
2. **Explain** the role of RNA in gene expression.
3. **Summarize** transcription.
4. **Explain** how codons determine the amino acid sequence of a protein.
5. **Describe** the steps of translation.
6. **Identify** a complexity of gene expression.

CRITICAL THINKING

7. **Inferring Relationships** Multiple codons can produce the same amino acid. What is the advantage of this redundancy?
8. **Relating Concepts** What amino acid is coded for by the mRNA codon CCU?

ALTERNATIVE ASSESSMENT

9. **Gene Poster** Research two methods used to sequence the nucleotides in a gene. Compare the two methods. Give examples of how this technology might be used in a clinical setting. Prepare a poster to summarize the two methods that you researched.

Answers to Section Review

1. Proteins are produced through a process that involves the transcription of information in the DNA into an mRNA strand in the nucleus, and then the translation of that information into the amino acid sequence of the protein.
2. Messenger RNA (mRNA) transcribes DNA's code and takes it to ribosomal RNA (rRNA) to direct the assembly of amino acids in the proper sequence, using transfer RNA (tRNA) as a "taxi" service.
3. The information contained in a sequence of DNA (gene) is written into the language of RNA, using RNA nucleotides to produce mRNA.
4. With four bases, three-letter combinations are needed to provide codes for twenty amino acids. Each three-letter combination is called a codon.
5. During translation, mRNA is read by the ribosome, calling for the delivery of specific amino acids by tRNA. Two tRNAs are positioned on the ribosome, allowing the amino acids to form a peptide bond.
6. Some traits require multiple genes to be expressed. Gene expression is also affected by timing and the cell's environment.
7. If an error occurs during translation, the codon may still signal the correct amino acid.
8. proline
9. Shotgun sequencing is used for sequencing longer strands of DNA. The older Sanger method is used for shorter fragments.

Skills Practice

Chapter 13 Lab

45 min

Objectives

- Extract DNA from wheat germ.
- Explain the role of detergents, heat, and alcohol in the extraction of DNA.

Materials

- wheat germ, raw (1 g)
- test tube or beaker (50 mL)
- water, hot tap (55°C, 20 mL)
- salt, table
- soap, liquid dishwashing (1 mL)
- isopropyl alcohol, cold (15 mL)
- glass rod, 8 cm long
- inoculating loop
- glass slide

Safety

DNA Extraction from Wheat Germ

The extraction and purification of DNA are the first steps in the analysis and manipulation of DNA. Very pure DNA can be easily extracted from cells in a research laboratory, and somewhat less pure DNA can be extracted with some simple techniques easily performed in a classroom.

The first step in extracting DNA from a cell is to lyse, or break open, the cell. Cell walls, cell membranes, and nuclear membranes are broken down by physical smashing, heating, and the addition of detergents. In water, DNA is soluble. When isopropyl alcohol is added, the DNA uncoils and precipitates, leaving behind many other cell components that are not soluble in isopropyl alcohol. The DNA can be then spooled, or wound onto an inoculating loop, and pulled from the solution. In this lab, you will extract the DNA from wheat germ. Wheat germ is simply the ground-up cells of wheat kernels, or seeds.

Procedure

1. Put on safety goggles, lab apron, and gloves.
2. **CAUTION: Glassware, such as a test tube, is fragile and can break.** Place 1 g of wheat germ into a clean test tube.
3. Add 20 mL hot (55°C) tap water and stir with glass rod for 2 to 3 min.
4. Next, add a pinch of table salt, and mix well.
5. Add a few drops (1 mL) of liquid dishwashing soap. Stir the mixture with the glass rod for 1 min until it is well mixed.
6. **CAUTION: Isopropyl alcohol is flammable. Bunsen burners and hot plates should be removed from the lab.** Slowly pour 15 mL cold isopropyl alcohol down the side of the tilted tube or beaker. The alcohol should form a top layer over the original solution. Note: Do not pour the alcohol too fast or directly into the wheat germ solution.
7. Tilt the tube upright, and watch the stringy, white material float up into the alcohol layer (this result should occur after 10 to 15 min). This material is the DNA from the wheat germ.
8. Carefully insert the inoculating loop into the white material in the alcohol layer. Gently twist the loop as you wind the DNA around the loop. Remove the loop from the tube, and tap the DNA onto a glass slide.
9. Clean up your lab materials according to your teacher's instructions. Wash your hands before leaving the lab.

Analyze and Conclude

1. **Describing Events** Describe the appearance of the DNA on the slide.
2. **Interpreting Information** Explain the role of detergent, heat, and isopropyl alcohol in the extraction of DNA.
3. SCIENTIFIC METHODS **Comparing Structures** How do the characteristics of your DNA sample relate to the structure of eukaryotic DNA?
4. SCIENTIFIC METHODS **Designing Experiments** Design a DNA extraction experiment in which you explore the effect of changing the variables.

Lab

Time Required

One 50-minute class period

Ratings

Teacher Prep	
Student Setup	
Concept Level	
Cleanup	

Safety Cautions

Students must wear the listed safety equipment to do this lab. Because they will be working with a flammable liquid, all heat and ignition sources must be removed from the area. Fumes can easily catch fire. Keep the total volume of alcohol in the room to a minimum.

Tips and Tricks

This lab works best in groups of two to four students. Set up 55°C hot-water baths for students ahead of time. Isopropyl alcohol should be kept cold, on ice or in a freezer, prior to use. Weigh out the wheat germ and detergent for each group prior to class to save time.

Hot (50–60°C) water will soften the membrane and denature deoxyribonuclease. This enzyme will cut DNA into small fragments. Seal the test tube with a rubber stopper. When swirling the detergent, use a gentle motion to avoid forming suds. *Cold* ethanol can be substituted for isopropanol. Using a piece of wire, with a hook, allows the DNA to be lifted very slowly from the test tube.

Answers to Analyze and Conclude

1. Students should describe the color as clear or white, and a viscosity that is similar to mucus. The length of the DNA sample may differ; it may be several short strands or a single giant thread. Some students may note its sticky texture and elastic nature.
2. Detergent breaks down and emulsifies the fat and proteins that make up the cell membrane and the nuclear membrane, causing the the DNA to be released into solution. Heat softens the cell and nuclear membranes and inactivates (denatures) some enzymes that cut DNA into small fragments. Alcohol causes the DNA to precipitate out of solution. This allows the DNA to be collected and helps to partially purify the DNA from other cellular components that are soluble in water but not alcohol.
3. The sample sticks to itself, which relates to the double helix structure. It also forms long strings, which relates to the fact that eukaryotic DNA is very long.
4. Answers will vary but should include how the characteristics of the alcohol, detergent, and water temperatures are related to their proposed roles in DNA extraction.

Key Resources

- Holt Lab Generator
- Lab Datasheet (Levels A, B, C)
- Holt Science Biology Video Labs
- Virtual Investigations

Chapter 13

SUPER SUMMARY

Have students connect the major concepts through an interactive Super Summary. Visit **go.hrw.com** and type in the keyword **HX8DNAS** to access the Super Summary for this chapter.

Reteaching Key Ideas

DNA Structure and Base-Pairing Group students into pairs and give them sets of index cards, with the components of DNA written on separate cards. Each set of cards should include at least sixteen sugars, sixteen phosphates and four of each of the bases. Ask students to arrange the cards in a pattern that shows the structure of DNA. LS Visual

Vocabulary Activity To help students with the vocabulary in this chapter, write the following terms on separate index cards: *amino acid, codon, anti-codon, DNA, mRNA, tRNA, rRNA, ribosome, transcription, translation.* Give a set of cards to each group of four students. Ask students to organize the cards and describe the connection between terms. Monitor the groups to check for accuracy. LS Verbal/Visual

Chapter 13 Summary

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SUPER SUMMARY
Keyword: HX8DNAS

Key Ideas	Key Terms

1 The Structure of DNA

- DNA is the primary material that causes recognizable, inheritable characteristics in related groups of organisms.
- Three major experiments led to the conclusion that DNA is the genetic material in cells. These experiments were performed by Griffith, Avery, Hershey, and Chase.
- A DNA molecule is shaped like a spiral staircase and is composed of two parallel strands of linked subunits.
- The information in DNA is contained in the order of the bases, while the base-pairing structure allows the information to be copied.
- Watson and Crick used information from experiments by Chargaff, Wilkins, and Franklin to determine the three-dimensional structure of DNA.

gene (293)
DNA (293)
nucleotide (296)
purine (297)
pyrimidine (297)

2 Replication of DNA

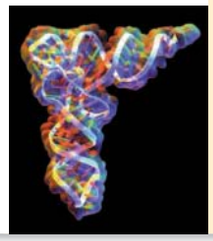
- In DNA replication, the DNA molecule unwinds, and the two sides split. Then, new bases are added to each side until two identical sequences result.
- The replication of DNA involves many proteins that form a machinelike complex of moving parts.
- In prokaryotic cells, replication starts at a single site. In eukaryotic cells, replication starts at many sites along the chromosome.

DNA replication (300)
DNA helicase (301)
DNA polymerase (301)

3 RNA and Gene Expression

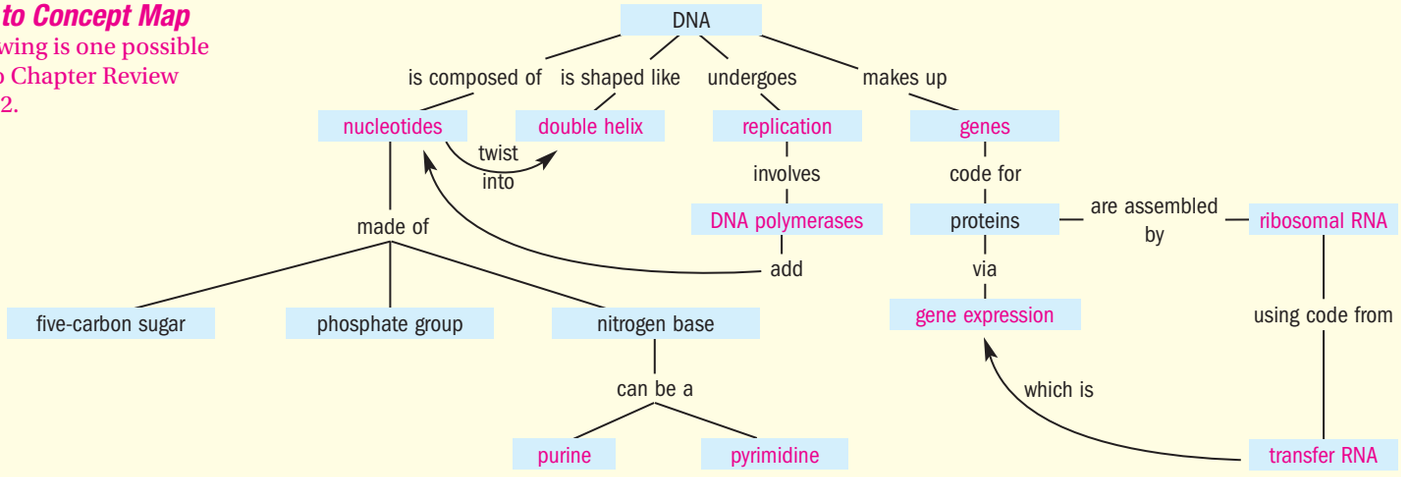
- Gene expression produces proteins by transcription and translation. This process takes place in two stages, both of which involve RNA.
- In cells, three types of RNA complement DNA and translate the genetic code into proteins.
- During transcription, the information in a gene is transcribed, or copied, into mRNA.
- The genetic code is based on codons that each represent a specific amino acid.
- Translation occurs in a sequence of steps, involves three kinds of RNA, and results in a complete polypeptide.
- Despite the neatness of the genetic code, every gene cannot be simply linked to a single outcome.

RNA (304)
gene expression (304)
transcription (305)
translation (305)
codon (307)



Answer to Concept Map

The following is one possible answer to Chapter Review question 2.



Chapter 13 Review

READING TOOLBOX

1. **Word Parts** Use the Word Parts exercise to identify and then understand the enzymes described in this chapter.
2. **Concept Mapping** Make a concept map that shows the structure of DNA and the way that DNA replicates. Try to include the following words in your concept map: *nucleotides, purine, pyrimidine, double helix, replication, transfer RNA, ribosomal RNA, gene expression, DNA polymerases,* and *gene.*

Using Key Terms

Use each of the following terms in a separate sentence.

3. *nucleotide*
4. *DNA replication*

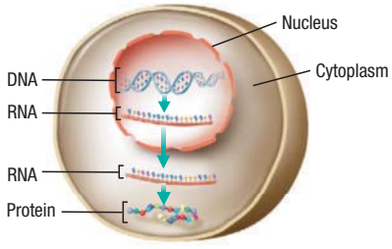
For each pair of terms, explain how the meanings of the terms differ.

5. *transcription* and *translation*
6. *gene* and *DNA*
7. *DNA helicase* and *DNA polymerase*

Understanding Key Ideas

8. What is the function of DNA?
   - **a.** DNA creates genetic material.
   - **b.** DNA controls all of the aspects of an organism's behavior.
   - **c.** DNA enables organisms to pass on genetic information to their offspring.
   - **d.** DNA enables organisms to produce offspring that are identical to their parents.
9. If the sequence of nitrogenous bases in one strand of DNA is GAGTC, what is the sequence of bases in the complementary strand of DNA?
   - **a.** AGACT
   - **b.** TCTGA
   - **c.** ATACG
   - **d.** CTCAG
10. Which of the following bases pairs with uracil in an RNA molecule?
    - **a.** adenine
    - **b.** guanine
    - **c.** thymine
    - **d.** cytosine
11. What was the significance of Frederick Griffith's experiments with DNA?
    - **a.** Griffith showed that DNA has a double-helix structure.
    - **b.** Griffith disproved the idea that DNA contained genetic material.
    - **c.** Griffith discovered that genetic material could be transferred between cells.
    - **d.** Griffith demonstrated that viruses could inject their DNA into bacterial cells.
12. What does the process of transcription produce?
    - **a.** tRNA
    - **b.** RNA
    - **c.** mRNA
    - **d.** DNA

Use the diagram to answer the following question.



13. This illustration shows a eukaryotic cell. Where does translation occur in this cell?
    - **a.** in the DNA
    - **b.** in the cytoplasm
    - **c.** in the nucleus
    - **d.** in the ribosome

Explaining Key Ideas

14. **Identify** the roles that proteins play in DNA replication.
15. **Compare** the structure of RNA with that of DNA.
16. **Determine** the kinds of events that can cause complications in gene expression.
17. **Relate** the role of codons to the sequence of amino acids that results after translation.

Assignment Guide

Section	Questions
1	3, 6, 8, 9, 11, 18, 24, 26, 29, 30, 31
2	4, 7, 14, 19, 20, 21, 22
3	5, 10, 12, 13, 15, 16, 17, 23, 25, 27, 28

Review

Reading Toolbox

1. DNA helicase: an enzyme that acts on the DNA helix configuration to break bonds between the nitrogen bases

   DNA polymerase: an enzyme that helps add nucleotides to form a new DNA molecule

   RNA polymerase: an enzyme that adds nucleotides as it reads the code of the gene
2. See previous page for answer to concept map.

Using Key Terms

3. Sample answer: *Nucleotides* form the backbone of the DNA staircase.
4. Sample answer: *DNA replication* creates two identical DNA molecules.
5. *Transcription* takes place in the nucleus and produces mRNA; *translation* takes place on the ribosome and involves mRNA, tRNA, and amino acids.
6. A *gene* is a section of *DNA* that codes for a polypeptide.
7. *DNA helicase* "unzips" a DNA molecule, breaking bonds; *DNA polymerase* makes bonds by joining nucleotides to existing bases while "proofreading" for accuracy.

Understanding Key Ideas

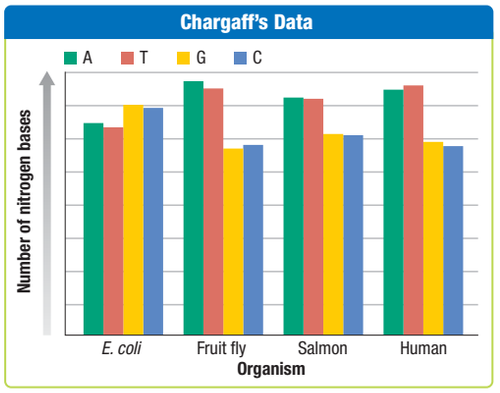
8. c 9. d 10. a 11. c
12. c 13. b

Explaining Key Ideas

14. DNA helicase breaks hydrogen bonds, allowing the DNA strands to disconnect. DNA polymerase bonds nucleotides to the exposed base pairs while proofreading the strand to eliminate mistakes.
15. RNA has ribose rather than deoxyribose. It contains the base uracil rather than thymine, and it is a single, rather than a double, strand.
16. Variations, mistakes, feedback, and other complex interactions among any parts of the processes of protein synthesis can affect gene expression.
17. The sequence of codons on mRNA determines the sequence of amino acids in translation.

Using Science Graphics

Use the table to answer the following question.



18. Chargaff collected data involving bases in DNA. Which of the following ratios most accurately expresses the relationship between adenine and thymine in DNA?

a. 1:2
b. 1:1
c. 2:1
d. 1:4

Critical Thinking

19. Predicting Outcomes What would happen if the enzymes that keep DNA strands separated during the replication process were not present?

20. Recognizing Relationships How might the process of DNA replication in eukaryotic cells lead to more errors than the process of DNA replication in prokaryotic cells does?

21. Relating Concepts How does a replication fork enable the process of DNA replication?

22. Justifying Conclusions Why does DNA replication in eukaryotic cells involve multiple replication forks?

23. Contrasting Functions Contrast the roles of mRNA and tRNA in the process of protein synthesis.

24. Evaluating Viewpoints How did Watson and Crick build on the discoveries of other scientists to determine the structure of DNA?

25. Proposing Alternative Hypotheses Propose one possible exception to the formula of "one gene → one protein → one trait."

Writing for Science

26. Speech Writing Imagine that you are asked to introduce Watson, Crick, and Wilkins at the Nobel Prize ceremony in 1962. Write a speech that details the work that contributed to the discovery of the structure of DNA.

Methods of Science

27. Forming Hypotheses Recall that mRNA has one start codon and three stop codons. Based on what you know about the process of gene expression, hypothesize why it would be beneficial to have only one start codon but three stop codons involved in this process.

Alternative Assessment

28. Brochure Human blood types are examples of the complex results of genes. Make a brochure entitled "A Guide to Human Blood Types for Blood Donors." Use reference sources to find out about the major blood types. Be sure to find out and explain why each blood type matters for blood-donating purposes and what the genetic determinants of each blood type are.

Math Skills

Use the table to answer the following questions.

Percentage of Each Nitrogen Base

	A	T	G	C
Human	30.4	30.1	19.6	19.9
Wheat	27.3	27.1	22.7	22.8
E. coli	24.7	23.6	26.0	25.7

29. Ratios What is the ratio of purines to pyrimidines?

30. Percentages Within each organism, which nucleotides are found in similar percentages?

31. Do the ratio and percentages in the previous two questions follow Chargaff's rule?

Using Science Graphics

18. b

Critical Thinking

19. replication would not occur

20. In eukaryotic cells, DNA replication occurs simultaneously in about 100 sections per chromosome, compared with only two replication forks in prokaryotes. There is more room for error.

21. A replication fork is a place where the strands of DNA are separated, allowing for the addition of new nucleotides by DNA polymerase.

22. Eukaryotic chromosomes are much longer than prokaryotic chromosomes, and need multiple replication forks. If eukaryotic cells used only one replication fork, it would take 33 days to replicate a single chromosome.

23. mRNA carries the code for making a protein from DNA (a gene). tRNA translates the codons by delivering the correct amino acids to join into a polypeptide.

24. Watson and Crick used Chargaff's research to determine the base-pairing. They used the X-ray diffraction photograph from Franklin and Wilkins to determine the physical arrangement of the bases in nucleotide strands that formed a double helix.

25. Accept all reasonable answers. For example, different protein combinations produce different traits.

Writing for Science

26. Make sure students accurately acknowledge contributors.

Methods of Science

27. It is advantageous to have only one start signal so that protein synthesis begins only at a specific location. There are multiple stop codons so that if a point mutation occurs, protein synthesis can still stop.

Alternative Assessment

28. Make sure that students understand that the purpose of this exercise is to show the sophistication of gene expression.

Math Skills

29. 1 to 1

30. For all three organisms, the adenine to thymine ratio is the same; the guanine to cytosine ratio is the same.

31. yes

Chapter 13 Standardized Test Prep

TEST TIP You can sometimes figure out an answer to a question before you look at the answer choices. After you answer the question in your mind, compare your answer with each answer choice. Choose the answer that most closely matches your own answer.

Science Concepts

1. During protein synthesis, transfer RNA (tRNA)
   - **A** produces a new RNA molecule.
   - **B** acts as a start signal for protein synthesis.
   - **C** produces protein subunits by translating the codons on mRNA.
   - **D** delivers the instructions for protein synthesis to the site of translation.

2. Erwin Chargaff's data on nitrogenous bases
   - **F** suggested that DNA bases are paired.
   - **G** suggested that DNA is a tightly coiled helix.
   - **H** suggested that certain bases are found in equal amounts in DNA.
   - **J** proved that DNA's structure is similar to a twisted ladder.

3. The immediate result of a mistake in transcription would most likely be a
   - **A** different cell.
   - **B** different gene.
   - **C** different protein.
   - **D** different set of alleles.

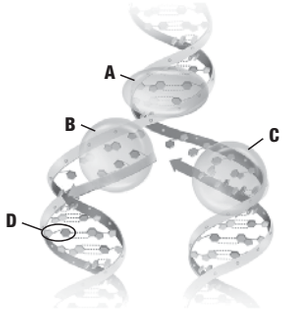
4. Which part of a nucleotide contains genetic information?
   - **F** sugar molecules
   - **G** nitrogen base pairs
   - **H** phosphate molecules
   - **J** deoxyribose molecules

Math Skills

5. **Calculating Percentages** DNA analysis reveals that adenine makes up 40% of a piece of DNA. What percentage of the DNA bases in the piece of DNA is guanine?
   - **A** 20%
   - **B** 60%
   - **C** 40%
   - **D** 10%

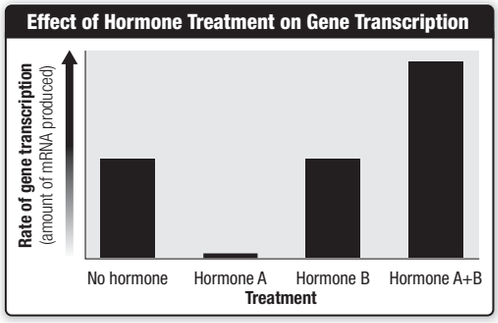
Using Science Graphics

Use the diagram to answer the following question.



6. What is the function of the structure labeled "A"?
   - **F** separating DNA strands
   - **G** reconnecting DNA strands
   - **H** checking the new DNA strands for errors
   - **J** adding nucleotides to make new DNA strands

Use the diagram to answer the following questions.



7. What is the control variable in this experiment?
   - **A** No Hormone
   - **B** Hormone A
   - **C** Hormone B
   - **D** Hormone A+B

8. What can you conclude about the effect Hormone B has on the rate of gene transcription compared to the control treatment?
   - **F** It increases gene transcription rate.
   - **G** It decreases gene transcription rate.
   - **H** It does not change gene transcription rate compared to the control.
   - **J** It has a smaller effect on transcription rate than Hormone A does.

State Resources

For specific resources for your state, visit go.hrw.com and type in the keyword **HSHSTR**.

Test Practice with Guided Reading Development

Answers

1. C	2. H	3. C
4. G	5. D	6. F
7. A	8. H	

TEST DOCTOR

Question 2 Chargaff data was the ratio of bases, so choices **G** and **J** are incorrect because they describe the structure of DNA. Choice **F** is incorrect because base pairing was a hypothesis based on Chargaff's data. Choice **H** is correct because Chargaff's work indicated that the bases A and T, G and C are found in equal amounts.

Question 3 The transcription process copies data from a gene to mRNA. The mRNA produces proteins through translation. Thus, choices **A, B,** and **D** are incorrect because the result is the production of a protein. Choice **C** is correct because a transcription error could code for another amino acid, thereby changing the protein produced.

Question 4 Choices **F** and **J** are incorrect because deoxyribose (sugar) is in all nucleotides. It cannot provide a code. Choice **H** is incorrect for the same reason. Phosphate is also a repetitive molecule. Choice **G** is correct because nitrogen base pairs vary and can provide a code.

Question 5 If 40% of DNA is adenine, there will be an equal amount (40%) of thymine. That leaves 20% to be divided equally between guanine and cytosine. There would be 10% guanine. Thus, choices **A, B,** and **C** are incorrect. Choice **D** is correct.