The color of this fawn is caused by a genetic trait called albinism. Albinism is the absence of body pigment. Notice that the fawn’s mother has brown fur, the normal fur color of an adult whitetail deer.

- Why do you think the fawn looks so different from its mother?
- What do you think determines the color of the offspring?
- How do you think traits are passed from generation to generation?
What do you think?
Before you read, decide if you agree or disagree with each of these statements. As you read this chapter, see if you change your mind about any of the statements.

1. Like mixing paints, parents’ traits always blend in their offspring.
2. If you look more like your mother than you look like your father, then you received more traits from your mother.
3. All inherited traits follow Mendel’s patterns of inheritance.
4. Scientists have tools to predict the form of a trait an offspring might inherit.
5. Any condition present at birth is genetic.
6. A change in the sequence of an organism’s DNA always changes the organism’s traits.
Mendel and His Peas

Have you ever seen a black ladybug? It is less common than the orange variety you might know, but both are the same species of beetle. So why do they look different? Believe it or not, a study of pea plants helped scientists explain these differences.
Have you ever mixed two paint colors to make a new color? Long ago, people thought an organism’s characteristics, or traits, mixed like colors of paint because offspring resembled both parents. This is known as blending inheritance.

Today, scientists know that heredity—the passing of traits from parents to offspring—is more complex. For example, you might have blue eyes but both of your parents have brown eyes. How does this happen? More than 150 years ago, Gregor Mendel, an Austrian monk, performed experiments that helped answer these questions and disprove the idea of blending inheritance. Because of his research, Mendel is known as the father of genetics—the study of how traits are passed from parents to offspring.

**Think About This**

1. Why might some students have types of traits that others do not have?
2. If a person has dimples, do you think his or her offspring will have dimples? Explain.
3. **Key Concept** What do you think determines the types of traits you inherit?

**Early Ideas About Heredity**

What makes you unique?

Traits such as eye color have many different types, but some traits have only two types. By a show of hands, determine how many students in your class have each type of trait below.

<table>
<thead>
<tr>
<th>Trait</th>
<th>Type 1</th>
<th>Type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earlobes</td>
<td>Unattached</td>
<td>Attached</td>
</tr>
<tr>
<td>Thumbs</td>
<td>Curved</td>
<td>Straight</td>
</tr>
<tr>
<td>Interlacing</td>
<td>Left thumb</td>
<td>Right thumb</td>
</tr>
<tr>
<td>fingers</td>
<td>over right thumb</td>
<td>over left thumb</td>
</tr>
</tbody>
</table>

**Word Origin**

*genetics* from Greek *genesis*, means “origin”
Mendel’s Experimental Methods

During the 1850s, Mendel studied genetics by doing controlled breeding experiments with pea plants. Pea plants were ideal for genetic studies because

• they reproduce quickly. This enabled Mendel to grow many plants and collect a lot of data.

• they have easily observed traits, such as flower color and pea shape. This enabled Mendel to observe whether or not a trait was passed from one generation to the next.

• Mendel could control which pairs of plants reproduced. This enabled him to determine which traits came from which plant pairs.

Pollination in Pea Plants

To observe how a trait was inherited, Mendel controlled which plants pollinated other plants. Pollination occurs when pollen lands on the pistil of a flower. Sperm cells from the pollen then can fertilize egg cells in the pistil. Pollination in pea plants can occur in two ways. Self-pollination occurs when pollen from one plant lands on the pistil of a flower on the same plant, as shown in Figure 1. Cross-pollination occurs when pollen from one plant reaches the pistil of a flower on a different plant. Cross-pollination occurs naturally when wind, water, or animals such as bees carry pollen from one flower to another. Mendel allowed one group of flowers to self-pollinate. With another group, he cross-pollinated the plants himself.
**True-Breeding Plants**

Mendel began his experiments with plants that were true-breeding for the trait he would test. When a true-breeding plant self-pollinates, it always produces offspring with traits that match the parent. For example, when a true-breeding pea plant with wrinkled seeds self-pollinates, it produces only plants with wrinkled seeds. In fact, plants with wrinkled seeds appear generation after generation.

**Mendel’s Cross-Pollination**

By cross-pollinating plants himself, Mendel was able to select which plants pollinated other plants. Figure 2 shows an example of a manual cross between a plant with white flowers and one with purple flowers.

Mendel cross-pollinated hundreds of plants for each set of traits, such as flower color—purple or white; seed color—green or yellow; and seed shape—round or wrinkled. With each cross-pollination, Mendel recorded the traits that appeared in the offspring. By testing such a large number of plants, Mendel was able to predict which crosses would produce which traits.

**Key Concept Check** Why did Mendel perform cross-pollination experiments?
Mendel’s Results

Once Mendel had enough true-breeding plants for a trait that he wanted to test, he cross-pollinated selected plants. His results are shown in Figure 3.

First-Generation Crosses

A cross between true-breeding plants with purple flowers produced plants with only purple flowers. A cross between true-breeding plants with white flowers produced plants with only white flowers. But something unexpected happened when Mendel crossed true-breeding plants with purple flowers and true-breeding plants with white flowers—all the offspring had purple flowers.

New Questions Raised

The results of the crosses between true-breeding plants with purple flowers and true-breeding plants with white flowers led to more questions for Mendel. Why did all the offspring always have purple flowers? Why were there no white flowers? Why didn’t the cross produce offspring with pink flowers—a combination of the white and purple flower colors? Mendel carried out more experiments with pea plants to answer these questions.

Reading Check

Predict the offspring of a cross between two true-breeding pea plants with smooth seeds.

First-Generation Crosses

Figure 3  Mendel crossed three combinations of true-breeding plants and recorded the flower colors of the offspring.

Purple $\times$ Purple

![Diagram]

All purple flowers (true-breeding)

White $\times$ White

![Diagram]

All white flowers (true-breeding)

Purple (true-breeding) $\times$ White (true-breeding)

![Diagram]

All purple flowers (hybrids)

Visual Check  Suppose you cross hundreds of true-breeding plants with purple flowers with hundreds of true-breeding plants with white flowers. Based on the results of this cross in the figure above, would any offspring produce white flowers? Explain.
Second-Generation (Hybrid) Crosses

The first-generation purple-flowering plants are called hybrid plants. This means they came from true-breeding parent plants with different forms of the same trait. Mendel wondered what would happen if he cross-pollinated two purple-flowering hybrid plants.

As shown in Figure 4, some of the offspring had white flowers, even though both parents had purple flowers. The results were similar each time Mendel cross-pollinated two hybrid plants. The trait that had disappeared in the first generation always reappeared in the second generation.

The same result happened when Mendel cross-pollinated pea plants for other traits. For example, he found that cross-pollinating a true-breeding yellow-seeded pea plant with a true-breeding green-seeded pea plant always produced yellow-seeded hybrids. A second-generation cross of two yellow-seeded hybrids always yielded plants with yellow seeds and plants with green seeds.

Reading Check What is a hybrid plant?

**Science Use v. Common Use**

**hybrid**

Science Use the offspring of two animals or plants with different forms of the same trait

Common Use having two types of components that perform the same function, such as a vehicle powered by both a gas engine and an electric motor

---

**Figure 4** Mendel cross-pollinated first-generation hybrid offspring to produce second-generation offspring. In each case, the trait that had disappeared from the first generation reappeared in the second generation.
More Hybrid Crosses

Mendel counted and recorded the traits of offspring from many experiments in which he cross-pollinated hybrid plants. Data from these experiments are shown in Table 1. He analyzed these data and noticed patterns. For example, from the data of crosses between hybrid plants with purple flowers, he found that the ratio of purple flowers to white flowers was about 3:1. This means purple-flowering pea plants grew from this cross three times more often than white-flowering pea plants grew from the cross. He calculated similar ratios for all seven traits he tested.

**Table 1 Results of Hybrid Crosses**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Trait and Number of Offspring</th>
<th>Trait and Number of Offspring</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flower color</td>
<td>Purple 705</td>
<td>White 224</td>
<td>3.15:1</td>
</tr>
<tr>
<td>Flower position</td>
<td>Axial (Side of stem) 651</td>
<td>Terminal (End of stem) 207</td>
<td>3.14:1</td>
</tr>
<tr>
<td>Seed color</td>
<td>Yellow 6,022</td>
<td>Green 2,001</td>
<td>3.01:1</td>
</tr>
<tr>
<td>Seed shape</td>
<td>Round 5,474</td>
<td>Wrinkled 1,850</td>
<td>2.96:1</td>
</tr>
<tr>
<td>Pod shape</td>
<td>Inflated (Smooth) 882</td>
<td>Constricted (Bumpy) 299</td>
<td>2.95:1</td>
</tr>
<tr>
<td>Pod color</td>
<td>Green 428</td>
<td>Yellow 152</td>
<td>2.82:1</td>
</tr>
<tr>
<td>Stem length</td>
<td>Long 787</td>
<td>Short 277</td>
<td>2.84:1</td>
</tr>
</tbody>
</table>

Math Skills

**Use Ratios**

A ratio is a comparison of two numbers or quantities by division. For example, the ratio comparing 6,022 yellow seeds to 2,001 green seeds can be written as follows:

\[
\frac{6,022}{2,001} \text{ or } 6,022 : 2,001
\]

To simplify the ratio, divide the first number by the second number.

\[
\frac{6,022}{2,001} = \frac{3}{1} \text{ or } 3:1
\]

**Practice**

There are 14 girls and 7 boys in a science class. Simplify the ratio.
Mendel’s Conclusions

After analyzing the results of his experiments, Mendel concluded that two genetic factors control each inherited trait. He also proposed that when organisms reproduce, each reproductive cell—sperm or egg—contributes one factor for each trait.

Key Concept Check  What did Mendel conclude about inherited traits?

Dominant and Recessive Traits

Recall that when Mendel cross-pollinated a true-breeding plant with purple flowers and a true-breeding plant with white flowers, the hybrid offspring had only purple flowers. Mendel hypothesized that the hybrid offspring had one genetic factor for purple flowers and one genetic factor for white flowers. But why were there no white flowers?

Mendel also hypothesized that the purple factor is the only factor seen or expressed because it blocks the white factor. A genetic factor that blocks another genetic factor is called a dominant (DAH muh nunt) trait. A dominant trait, such as purple pea flowers, is observed when offspring have either one or two dominant factors. A genetic factor that is blocked by the presence of a dominant factor is called a recessive (rih SE silhv) trait. A recessive trait, such as white pea flowers, is observed only when two recessive genetic factors are present in offspring.

From Parents to Second Generation

For the second generation, Mendel cross-pollinated two hybrids with purple flowers. About 75 percent of the second-generation plants had purple flowers. These plants had at least one dominant factor. Twenty-five percent of the second-generation plants had white flowers. These plants had the same two recessive factors.

Key Concept Check  How do dominant and recessive factors interact?

FOLDABLES

Make a vertical two-tab book and label it as shown. Use it to organize your notes on dominant and recessive factors.

Which is the dominant trait?

Imagine you are Gregor Mendel’s lab assistant studying pea plant heredity. Mendel has crossed true-breeding plants with axial flowers and true-breeding plants with terminal flowers. Use the data below to determine which trait is dominant.

<table>
<thead>
<tr>
<th>Pea Flower Location Results</th>
<th>Axial (Number of Offspring)</th>
<th>Terminal (Number of Offspring)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>794</td>
<td>0</td>
</tr>
<tr>
<td>Second</td>
<td>651</td>
<td>207</td>
</tr>
</tbody>
</table>

Analyze and Conclude

1. Determine which trait is dominant and which trait is recessive. Support your answer with data.
2. Key Concept  Analyze the first-generation data. What evidence do you have that one trait is dominant over the other?
Lesson 1 Review

Visual Summary
Genetics is the study of how traits are passed from parents to offspring.

Mendel studied genetics by doing cross-breeding experiments with pea plants.

Mendel's experiments with pea plants showed that some traits are dominant and others are recessive.

Use Vocabulary
1. Distinguish between heredity and genetics.
2. Define the terms dominant and recessive.
3. Use the term recessive in a complete sentence.

Understand Key Concepts
4. A recessive trait is observed when an organism has _______ recessive genetic factor(s).
   A. 0 C. 2
   B. 1 D. 3

5. Summarize Mendel’s conclusions about how traits pass from parents to offspring.

6. Describe how Mendel cross-pollinated pea plants.

Interpret Graphics
7. Suppose the two true-breeding plants shown below were crossed.

What color would the flowers of the offspring be? Explain.

Critical Thinking
8. Design an experiment to test for true-breeding plants.
9. Examine how Mendel’s conclusions disprove blending inheritance.

Math Skills
10. A cross between two pink camellia plants produced the following offspring: 7 plants with red flowers, 7 with white flowers, and 14 with pink flowers. What is the ratio of red to white to pink?
Gregor Mendel—monk, scientist, gardener, and beekeeper—was a keen observer of the world around him. Curious about how traits pass from one generation to the next, he grew and tested almost 30,000 pea plants. Today, Mendel is called the father of genetics. After Mendel published his findings, however, his “laws of heredity” were overlooked for several decades.

In 1900, three European scientists, working independently of one another, rediscovered Mendel’s work and replicated his results. Then, other biologists quickly began to recognize the importance of Mendel’s work.

1902: American physician Walter Sutton demonstrates that Mendel’s laws of inheritance can be applied to chromosomes. He concludes that chromosomes contain a cell’s hereditary material on genes.

1952: American geneticists Martha Chase and Alfred Hershey prove that DNA transmits inherited traits from one generation to the next.

1953: Francis Crick and James Watson determine the structure of the DNA molecule. Their work begins the field of molecular biology and leads to important scientific and medical research in genetics.

2003: The National Human Genome Research Institute (NHGRI) completes mapping and sequencing human DNA. Researchers and scientists are now trying to discover the genetic basis for human health and disease.

RESEARCH What are some genetic diseases? Report on how genome-based research might help cure these diseases in the future.
Lesson 2

Reading Guide

Key Concepts

ESSENTIAL QUESTIONS

• What determines the expression of traits?
• How can inheritance be modeled?
• How do some patterns of inheritance differ from Mendel’s model?

Vocabulary

gene
allele
phenotype
genotype
homozygous
heterozygous
Punnett square
incomplete dominance
codominance
polygenic inheritance

Make the Connection

Physical traits, such as those shown in these eyes, can vary widely from person to person. Take a closer look at the eyes on this page. What traits can you identify among them? How do they differ?
What controls traits?

Mendel concluded that two factors—one from each parent—control each trait. Mendel hypothesized that one factor came from the egg cell and one factor came from the sperm cell. What are these factors? How are they passed from parents to offspring?

Chromosomes

When other scientists studied the parts of a cell and combined Mendel’s work with their work, these factors were more clearly understood. Scientists discovered that inside each cell is a nucleus that contains thread-like structures called chromosomes. Over time, scientists learned that chromosomes contain genetic information that controls traits. We now know that Mendel’s “factors” are part of chromosomes and that each cell in offspring contains chromosomes from both parents. As shown in Figure 5, these chromosomes exist as pairs—one chromosome from each parent.

Figure 5 Humans have 23 pairs of chromosomes. Each pair has one chromosome from the father and one chromosome from the mother.

Launch Lab

What is the span of your hand?

Mendel discovered some traits have a simple pattern of inheritance—dominant or recessive. However, some traits, such as eye color, have more variation. Is human hand span a Mendelian trait?

1. Read and complete a lab safety form.
2. Use a metric ruler to measure the distance (in cm) between the tips of your thumb and little finger with your hand stretched out.
3. As a class, record everyone’s name and hand span in a data table.

Think About This

1. What range of hand span measurements did you observe?
2. **Key Concept** Do you think hand span is a simple Mendelian trait like pea plant flower color?
**Genes and Alleles**

Scientists have discovered that each chromosome can have information about hundreds or even thousands of traits. A gene (JEEN) is a section on a chromosome that has genetic information for one trait. For example, a gene of a pea plant might have information about flower color. Recall that an offspring inherits two genes (factors) for each trait—one from each parent. The genes can be the same or different, such as purple or white for pea flower color. *The different forms of a gene are called alleles* (uh LEELs). Pea plants can have two purple alleles, two white alleles, or one of each allele. In Figure 6, the chromosome pair has information about three traits—flower position, pod shape, and stem length.

**Reading Check** How many alleles controlled flower color in Mendel's experiments?

**Genotype and Phenotype**

Look again at the photo at the beginning of this lesson. What human trait can you observe? You might observe that eye color can be shades of blue or brown. Geneticists call how a trait appears, or is expressed, the trait’s phenotype (FEE nuh tipe). What other phenotypes can you observe in the photo?

Mendel concluded that two alleles control the expression or phenotype of each trait. *The two alleles that control the phenotype of a trait are called the trait’s genotype* (JEE nuh tipe). Although you cannot see an organism’s genotype, you can make inferences about a genotype based on its phenotype. For example, you have already learned that a pea plant with white flowers has two recessive alleles for that trait. These two alleles are its genotype. The white flower is its phenotype.

**Figure 6** The alleles for flower position are the same on both chromosomes. However, the chromosome pair has different alleles for pod shape and stem length.

---

**WORD ORIGIN**

*phenotype* from Greek *phainein*, means “to show”
Symbols for Genotypes  Scientists use symbols to represent the alleles in a genotype. In genetics, uppercase letters represent dominant alleles and lowercase letters represent recessive alleles. Table 2 shows the possible genotypes for both round and wrinkled seed phenotypes. Notice that the dominant allele, if present, is written first.

<table>
<thead>
<tr>
<th>Phenotypes (observed traits)</th>
<th>Genotypes (alleles of a gene)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Round</td>
<td>Homozygous dominant (RR)</td>
</tr>
<tr>
<td></td>
<td>Heterozygous (Rr)</td>
</tr>
<tr>
<td>Wrinkled</td>
<td>Homozygous recessive (rr)</td>
</tr>
</tbody>
</table>

A round seed can have two genotypes—RR and Rr. Both genotypes have a round phenotype. Why does Rr result in round seeds? This is because the round allele (R) is dominant to the wrinkled allele (r).

A wrinkled seed has the recessive genotype, rr. The wrinkled-seed phenotype is possible only when the same two recessive alleles (rr) are present in the genotype.

Homozygous and Heterozygous  When the two alleles of a gene are the same, its genotype is homozygous (hoh muh ZI gus). Both RR and rr are homozygous genotypes, as shown in Table 2.

If the two alleles of a gene are different, its genotype is heterozygous (he tuh roh ZI gus). Rr is a heterozygous genotype.

Key Concept Check  How do alleles determine the expression of traits?
Modeling Inheritance

Have you ever flipped a coin and guessed heads or tails? Because a coin has two sides, there are only two possible outcomes—heads or tails. You have a 50 percent chance of getting heads and a 50 percent chance of getting tails. The chance of getting an outcome can be represented by a ratio. The ratio of heads to tails is 50:50 or 1:1.

**Reading Check** What does a ratio of 2:1 mean?

Plant breeders and animal breeders use a method for predicting how often traits will appear in offspring that does not require performing the crosses thousands of times. Two models—a Punnett square and a pedigree—can be used to predict and identify traits among genetically related individuals.

**Punnett Squares**

If the genotypes of the parents are known, then the different genotypes and phenotypes of the offspring can be predicted. A **Punnett square** is a model used to predict possible genotypes and phenotypes of offspring. Follow the steps in **Figure 7** to learn how to make a Punnett square.

**Analyzing a Punnett Square**

**Figure 7** shows an example of a cross between two pea plants that are heterozygous for pea seed color—Yy and Yy. Yellow is the dominant allele—Y. Green is the recessive allele—y. The offspring can have one of three genotypes—YY, Yy, or yy. The ratio of genotypes is written as 1:2:1.

Because YY and Yy represent the same phenotype—yellow—the offspring can have one of only two phenotypes—yellow or green. The ratio of phenotypes is written 3:1. Therefore, about 75 percent of the offspring of the cross between two heterozygous pea plants will produce yellow seeds. About 25 percent of the plants will produce green seeds.
Using Ratios to Predict

Given a 3:1 ratio, you can expect that an offspring from heterozygous parents has a 3:1 chance of having yellow seeds. But you cannot expect that a group of four seeds will have three yellow seeds and one green seed. This is because one offspring does not affect the phenotype of another offspring. In a similar way, the outcome of one coin toss does not affect the outcome of other coin tosses.

However, if you counted large numbers of offspring from a particular cross, the overall ratio would be close to the ratio predicted by a Punnett square. Mendel did not use Punnett squares. However, by studying nearly 30,000 pea plants, his ratios nearly matched those that would have been predicted by a Punnett square for each cross.

Pedigrees

Another model that can show inherited traits is a pedigree. A pedigree shows phenotypes of genetically related family members. It can also help determine genotypes. In the pedigree in Figure 8, three offspring have a trait—attached ear-lobes—that the parents do not have. If these offspring received one allele for this trait from each parent, but neither parent displays the trait, the offspring must have received two recessive alleles.

Key Concept Check How can inheritance be modeled?

Pedigree

Figure 8 In this pedigree, the parents and two offspring have unattached ear lobes—the dominant phenotype. Three offspring have attached ear lobes—the recessive phenotype.

Attached lobe

Recessive phenotype

Female with attached lobes

Male with attached lobes

Dominant phenotype

Female with unattached lobes

Male with unattached lobes

Unattached lobe

Visual Check If the genotype of the offspring with attached lobes is uu, what is the genotype of the parents? How can you tell?
Complex Patterns of Inheritance

By chance, Mendel studied traits only influenced by one gene with two alleles. However, we know now that some inherited traits have complex patterns of inheritance.

Types of Dominance

Recall that for pea plants, the presence of one dominant allele produces a dominant phenotype. However, not all allele pairs have a dominant-recessive interaction.

Incomplete Dominance Sometimes traits appear to be combinations of alleles. Alleles show incomplete dominance when the offspring's phenotype is a combination of the parents' phenotypes. For example, a pink camellia, as shown in Figure 9, results from incomplete dominance. A cross between a camellia plant with white flowers and a camellia plant with red flowers produces only camellia plants with pink flowers.

Codominance The coat color of some cows is an example of another type of interaction between two alleles. When both alleles can be observed in a phenotype, this type of interaction is called codominance. If a cow inherits the allele for white coat color from one parent and the allele for red coat color from the other parent, the cow will have both red and white hairs.

Figure 9 In incomplete dominance, neither parent's phenotype is visible in the offspring's phenotype. In codominance, both parents' phenotypes are visible separately in the offspring's phenotype.
Multiple Alleles

Unlike the genes in Mendel’s pea plants, some genes have more than two alleles, or multiple alleles. Human ABO blood type is an example of a trait that is determined by multiple alleles. There are three different alleles for the ABO blood type—\(I^A\), \(I^B\), and \(i\). The way the alleles combine results in one of four blood types—A, B, AB, or O. The \(I^A\) and \(I^B\) alleles are codominant to each other, but they both are dominant to the \(i\) allele. Even though there are multiple alleles, a person can inherit only two of these alleles—one from each parent, as shown in Table 3.

Polygenic Inheritance

Mendel concluded that each trait was determined by only one gene. However, we now know that a trait can be affected by more than one gene. Polygenic inheritance occurs when multiple genes determine the phenotype of a trait. Because several genes determine a trait, many alleles affect the phenotype even though each gene has only two alleles. Therefore, polygenic inheritance has many possible phenotypes.

Look again at the photo at the beginning of this lesson. Eye color in humans is an example of polygenic inheritance. There are also many phenotypes for height in humans, as shown in Figure 10. Other human characteristics determined by polygenic inheritance are weight and skin color.

Key Concept Check

How does polygenic inheritance differ from Mendel’s model?

---

**Table 3 Human ABO Blood Types**

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Possible Genotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A</td>
<td>(I^A I^A) or (I^A i)</td>
</tr>
<tr>
<td>Type B</td>
<td>(I^B I^B) or (I^B i)</td>
</tr>
<tr>
<td>Type O</td>
<td>(ii)</td>
</tr>
<tr>
<td>Type AB</td>
<td>(I^A I^B)</td>
</tr>
</tbody>
</table>

---

**Figure 10** The eighth graders in this class have different heights.
Genes and the Environment

You read earlier in this lesson that an organism’s genotype determines its phenotype. Scientists have learned that genes are not the only factors that can affect phenotypes. An organism’s environment can also affect its phenotype. For example, the flower color of one type of hydrangea is determined by the soil in which the hydrangea plant grows. Figure 11 shows that acidic soil produces blue flowers and basic, or alkaline, soil produces pink flowers. Other examples of environmental effects on phenotype are also shown in Figure 11.

For humans, healthful choices can also affect phenotype. Many genes affect a person’s chances of having heart disease. However, what a person eats and the amount of exercise he or she gets can influence whether heart disease will develop.

Reading Check What environmental factors affect phenotype?

Siamese cats have alleles that produce a dark pigment only in cooler areas of the body. That’s why a Siamese cat’s ear tips, nose, paws, and tail are darker than other areas of its body.

The wing patterns of the map butterfly, Araschnia levana, depend on what time of year the adult develops. Adults that developed in the spring have more orange in their wings than those that developed in the summer.

These hydrangea plants are genetically identical. The plant grown in acidic soil produced blue flowers. The plant grown in alkaline soil produced pink flowers.
Lesson 2 Review

Visual Summary

- The genes for traits are located on chromosomes.

- Geneticists use Punnett squares to predict the possible genotypes and phenotypes of offspring.

- In polygenic inheritance, traits are determined by more than one gene and have many possible phenotypes.

FOLDABLES

Use your lesson Foldable to review the lesson. Save your Foldable for the project at the end of the chapter.

Use Vocabulary

1. Use the terms phenotype and genotype in a complete sentence.

2. Contrast homozygous and heterozygous.

3. Define incomplete dominance in your own words.

Understand Key Concepts

4. How many alleles control a Mendelian trait, such as pea seed color?
   - A. one
   - B. two
   - C. three
   - D. four

5. Explain where the alleles for a given trait are inherited from.

6. Describe how the genotypes RR and Rr result in the same phenotype.

7. Summarize how polygenic inheritance differs from Mendelian inheritance.

Interpret Graphics

8. Analyze this pedigree. If □ represents a male with the homozygous recessive genotype (aa), what is the mother’s genotype?

Critical Thinking

9. Predict the possible blood genotypes of a child, using the table below, if one parent is type O and the other parent is type A.

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Genotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood Type O</td>
<td>ii</td>
</tr>
<tr>
<td>Blood Type A</td>
<td>F^3F^0 or F^3i</td>
</tr>
</tbody>
</table>
How can you use Punnett squares to model inheritance?

Geneticists use models to explain how traits are inherited from one generation to the next. A simple model of Mendelian inheritance is a Punnett square. A Punnett square is a model of reproduction between two parents and the possible genotypes and phenotypes of the resulting offspring. It also models the probability that each genotype will occur.

Learn It

In science, a **model** is a representation of how something in the natural world works. A model is used to explain or predict a natural process. Maps, diagrams, three-dimensional representations, and mathematical formulas can all be used to help model nature.

Try It

1. Copy the Punnett square on this page in your Science Journal. Use it to complete a cross between a fruit fly with straight wings ($cc$) and a fruit fly with curly wings ($CC$).
2. According to your Punnett square, which genotypes are possible in the offspring?
3. Using the information in your Punnett square, calculate the ratio of the dominant phenotype to the recessive phenotype in the offspring.

Apply It

4. Based on the information in your Punnett square, how many offspring will have curly wings? Straight wings?
5. If you switch the locations of the parent genotypes around the Punnett square, does it affect the potential genotypes of their offspring? Explain.
6. **Key Concept** Design and complete a Punnett square to model a cross between two fruit flies that are heterozygous for the curly wings ($Cc$). What are the phenotypic ratios of the offspring?
Lesson 3

DNA and Genetics

**Reading Guide**

**Key Concepts**

**ESSENTIAL QUESTIONS**

- What is DNA?
- What is the role of RNA in protein production?
- How do changes in the sequence of DNA affect traits?

**Vocabulary**

- DNA
- nucleotide
- replication
- RNA
- transcription
- translation
- mutation

What are these coils?

What color are your eyes? How tall are you? Traits are controlled by genes. But genes never leave the nucleus of the cell. How does a gene control a trait? These stringy coils hold the answer to that question.
How are codes used to determine traits?

Interpret this code to learn more about how an organism’s body cells use codes to determine genetic traits.

1. Analyze the pattern of the simple code shown to the right. For example, □□□□ = DOG
2. In your Science Journal, record the correct letters for the symbols in the code below.

Think About This
1. What do all codes, such as Morse code and Braille, have in common?
2. What do you think might happen if there is a mistake in the code?
3. Key Concept How do you think an organism’s cells might use code to determine its traits?

The Structure of DNA

Have you ever put together a toy or a game for a child? If so, it probably came with directions. Cells put molecules together in much the same way you might assemble a toy. They follow a set of directions.

Genes provide directions for a cell to assemble molecules that express traits such as eye color or seed shape. Recall from Lesson 2 that a gene is a section of a chromosome. Chromosomes are made of proteins and deoxyribonucleic (dee AHK sih ri boh noo klee ihk) acid, or DNA—an organism’s genetic material. A gene is a segment of DNA on a chromosome.

Cells and organisms contain millions of different molecules. Countless numbers of directions are needed to make all those molecules. How do all these directions fit on a few chromosomes? The information, or directions, needed for an organism to grow, maintain itself, and reproduce is contained in DNA. As shown in Figure 12, strands of DNA in a chromosome are tightly coiled, like a telephone cord or a coiled spring. This coiling allows more genes to fit in a small space.

Key Concept Check What is DNA?

Figure 12 Strands of DNA are tightly coiled in chromosomes.
A Complex Molecule

What’s the best way to fold clothes so they will fit into a drawer or a suitcase? Scientists asked a similar question about DNA. What is the shape of the DNA molecule, and how does it fit into a chromosome? The work of several scientists revealed that DNA is like a twisted zipper. This twisted zipper shape is called a double helix. A model of DNA’s double helix structure is shown in Figure 13.

How did scientists make this discovery? Rosalind Franklin and Maurice Wilkins were two scientists in London who used X-rays to study DNA. Some of the X-ray data indicated that DNA has a helix shape.

American scientist James Watson visited Franklin and Wilkins and saw one of the DNA X-rays. Watson realized that the X-ray gave valuable clues about DNA’s structure. Watson worked with an English scientist, Francis Crick, to build a model of DNA. Watson and Crick based their work on information from Franklin’s and Wilkins’s X-rays. They also used chemical information about DNA discovered by another scientist, Erwin Chargaff. After several tries, Watson and Crick built a model that showed how the smaller molecules of DNA bond together and form a double helix.

Four Nucleotides Shape DNA

DNA’s twisted-zipper shape is because of molecules called nucleotides. A nucleotide is a molecule made of a nitrogen base, a sugar, and a phosphate group. Sugar-phosphate groups form the sides of the DNA zipper. The nitrogen bases bond and form the teeth of the zipper. As shown in Figure 13, there are four nitrogen bases: adenine (A), cytosine (C), thymine (T), and guanine (G). A and T always bond together, and C and G always bond together.

Reading Check What is a nucleotide?
How DNA Replicates

Cells contain DNA in chromosomes. So, every time a cell divides, all chromosomes must be copied for the new cell. The new DNA is identical to existing DNA. The process of copying a DNA molecule to make another DNA molecule is called replication. You can follow the steps of DNA replication in Figure 14. First, the strands separate in many places, exposing individual bases. Then nucleotides are added to each exposed base. This produces two identical strands of DNA.

Reading Check What is replication?

MiniLab

How can you model DNA? Making a model of DNA can help you understand its structure.

1. Read and complete a lab safety form.
2. Link a small paper clip to a large paper clip. Repeat four more times, making a chain of 10 paper clips.
3. Choose four colors of chenille stems. Each color represents one of the four nitrogen bases. Record the color of each nitrogen base in your Science Journal.
4. Attach a chenille stem to each large paper clip.
5. Repeat step 2 and step 4, but this time attach the corresponding chenille-stem nitrogen bases. Connect the nitrogen bases.
6. Securely insert one end of your double chain into a block of styrene foam.
7. Repeat step 6 with the other end of your chain.
8. Gently turn the blocks to form a double helix.

Analyze and Conclude

1. Explain which part of a DNA molecule is represented by each material you used.
2. Predict what might happen if a mistake were made in creating a nucleotide.
3. Key Concept How did making a model of DNA help you understand its structure?
Making Proteins

Recall that proteins are important for every cellular process. The DNA of each cell carries a complete set of genes that provides instructions for making all the proteins a cell requires. Most genes contain instructions for making proteins. Some genes contain instructions for when and how quickly proteins are made.

Junk DNA

As you have learned, all genes are segments of DNA on a chromosome. However, you might be surprised to learn that most of your DNA is not part of any gene. For example, about 97 percent of the DNA on human chromosomes does not form genes. Segments of DNA that are not parts of genes are often called junk DNA. It is not yet known whether junk DNA segments have functions that are important to cells.

The Role of RNA in Making Proteins

How does a cell use the instructions in a gene to make proteins? Proteins are made with the help of ribonucleic acid (RNA)—a type of nucleic acid that carries the code for making proteins from the nucleus to the cytoplasm. RNA also carries amino acids around inside a cell and forms a part of ribosomes.

RNA, like DNA, is made of nucleotides. However, there are key differences between DNA and RNA. DNA is double-stranded, but RNA is single-stranded. RNA has the nitrogen base uracil (U) instead of thymine (T) and the sugar ribose instead of deoxyribose.

The first step in making a protein is to make mRNA from DNA. The process of making mRNA from DNA is called **transcription**. Figure 15 shows how mRNA is transcribed from DNA.

**Key Concept Check** What is the role of RNA in protein production?

---

**Figure 15** Transcription is the first step in making a protein. During transcription, the sequence of nitrogen bases on a gene determines the sequence of bases on mRNA.
Three Types of RNA

On the previous page, you read about messenger RNA (mRNA). There are two other types of RNA, transfer RNA (tRNA) and ribosomal RNA (rRNA). Figure 16 illustrates how the three work together to make proteins. The process of making a protein from RNA is called translation. Translation occurs in ribosomes. Recall that ribosomes are cell organelles that are attached to the rough endoplasmic reticulum (rough ER). Ribosomes are also in a cell’s cytoplasm.

Translating the RNA Code

Making a protein from mRNA is like using a secret code. Proteins are made of amino acids. The order of the nitrogen bases in mRNA determines the order of the amino acids in a protein. Three nitrogen bases on mRNA form the code for one amino acid.

Each series of three nitrogen bases on mRNA is called a codon. There are 64 codons, but only 20 amino acids. Some of the codons code for the same amino acid. One of the codons codes for an amino acid that is the beginning of a protein. This codon signals that translation should start. Three of the codons do not code for any amino acid. Instead, they code for the end of the protein. They signal that translation should stop.

Reading Check  What is a codon?
Mutations

You have read that the sequence of nitrogen bases in DNA determines the sequence of nitrogen bases in mRNA, and that the mRNA sequence determines the sequence of amino acids in a protein. You might think these sequences always stay the same, but they can change. A change in the nucleotide sequence of a gene is called a mutation.

The 46 human chromosomes contain between 20,000 and 25,000 genes that are copied during DNA replication. Sometimes, mistakes can happen during replication. Most mistakes are corrected before replication is completed. A mistake that is not corrected can result in a mutation. Mutations can be triggered by exposure to X-rays, ultraviolet light, radioactive materials, and some kinds of chemicals.

Types of Mutations

There are several types of DNA mutations. Three types are shown in Figure 17. In a deletion mutation, one or more nitrogen bases are left out of the DNA sequence. In an insertion mutation, one or more nitrogen bases are added to the DNA. In a substitution mutation, one nitrogen base is replaced by a different nitrogen base.

Each type of mutation changes the sequence of nitrogen base pairs. This can cause a mutated gene to code for a different protein than a normal gene. Some mutated genes do not code for any protein. For example, a cell might lose the ability to make one of the proteins it needs.

Visual Check Which base pairs were omitted during replication in the deletion mutation?

Figure 17 Three types of mutations are substitution, insertion, and deletion.
Results of a Mutation

The effects of a mutation depend on where in the DNA sequence the mutation happens and the type of mutation. Proteins express traits. Because mutations can change proteins, they can cause traits to change. Some mutations in human DNA cause genetic disorders, such as those described in Table 4.

However, not all mutations have negative effects. Some mutations don’t cause changes in proteins, so they don’t affect traits. Other mutations might cause a trait to change in a way that benefits the organism.

Key Concept Check  How do changes in the sequence of DNA affect traits?

Scientists still have much to learn about genes and how they determine an organism’s traits. Scientists are researching and experimenting to identify all genes that cause specific traits. With this knowledge, we might be one step closer to finding cures and treatments for genetic disorders.

<table>
<thead>
<tr>
<th>Table 4 Genetic Disorders</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Defective Gene or Chromosome</strong></td>
</tr>
<tr>
<td>Chromosome 12, PAH gene</td>
</tr>
<tr>
<td>Chromosome 7, CFTR gene</td>
</tr>
<tr>
<td>Chromosome 7, elastin gene</td>
</tr>
<tr>
<td>Chromosome 17, BRCA 1; Chromosome 13, BRCA 2</td>
</tr>
</tbody>
</table>
DNA is a complex molecule that contains the code for an organism's genetic information.

RNA carries the codes for making proteins.

An organism’s nucleotide sequence can change through the deletion, insertion, or substitution of nitrogen bases.

Use your lesson Foldable to review the lesson. Save your Foldable for the project at the end of the chapter.

Use Vocabulry

1. Distinguish between transcription and translation.
2. Use the terms DNA and nucleotide in a sentence.
3. A change in the sequence of nitrogen bases in a gene is called a(n) ________

Understand Key Concepts

4. Where does the process of transcription occur?
   A. cytoplasm  C. cell nucleus
   B. ribosomes  D. outside the cell

5. Illustrate Make a drawing that illustrates the process of translation.

6. Distinguish between the sides of the DNA double helix and the teeth of the DNA double helix.

Interpret Graphics

7. Identify The products of what process are shown in the figure below?

Sequence Draw a graphic organizer like the one below about important steps in making a protein, beginning with DNA and ending with protein.

Critical Thinking

9. Hypothesize What would happen if a cell were unable to make mRNA?

10. Assess What is the importance of DNA replication occurring without any mistakes?
Imagine you are on a team of geneticists that is doing “cross-breeding experiments” with gummy bears. Unfortunately, the computer containing your data has crashed. All you have left are six gummy-bear litters that resulted from six sets of parents. But no one can remember which parents produced which litter. You know that gummy-bear traits have either Mendelian inheritance or incomplete dominance. Can you determine which parents produced each set of offspring and how gummy bear traits are inherited?

Ask a Question
What are the genotypes and phenotypes of the parents for each litter?

Make Observations
1. Obtain a bag of gummy bears. Sort the bears by color (phenotype).
   
   *Do not eat the gummy bears.*

2. Count the number (frequency) of bears for each phenotype. Then, calculate the ratio of phenotypes for each litter.

3. Combine data from your litter with those of your classmates using a data table like the one below.

4. As a class, select a letter to represent the alleles for color. Record the possible genotypes for your bears in the class data table.

<table>
<thead>
<tr>
<th>Cross #</th>
<th>Phenotype Frequencies</th>
<th>Ratio</th>
<th>Possible Genotypes</th>
<th>Made of Inheritance</th>
<th>Predicted Parental Genotypes</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXAMPLE</td>
<td>15 green/5 pink</td>
<td>3:1</td>
<td>GG or Gg/gg</td>
<td>Mendelian</td>
<td>Gg x Gg</td>
</tr>
<tr>
<td>1.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Form a Hypothesis
5 Use the data to form a hypothesis about the probable genotypes and phenotypes of the parents of your litter and the probable type of inheritance.

Test Your Hypothesis
6 Design and complete a Punnett square using the predicted parental genotypes in your hypothesis.
7 Compare your litter’s phenotype ratio with the ratio predicted by the Punnett square. Do your data support your hypothesis? If not, revise your hypothesis and repeat steps 5–7.

Analyze and Conclude
8 Infer What were the genotypes of the parents? The phenotypes? How do you know?
9 The Big Idea Determine the probable modes of inheritance for each phenotype. Explain your reasoning.
10 Graph Using the data you collected, draw a bar graph that compares the phenotype frequency for each gummy bear phenotype.

Communicate Your Results
Create a video presentation of the results of your lab. Describe the question you investigated, the steps you took to answer the question, and the data that support your conclusions. Share your video with your classmates.

Think of a question you have about genetics. For example, can you design a pedigree to trace a Mendelian trait in your family? To investigate your question, design a controlled experiment or an observational study.

Reminder
Using Ratios
- A ratio is a comparison of two numbers.
- A ratio of 15:5 can be reduced to 3:1.
### Key Concepts Summary

**Lesson 1: Mendel and His Peas**
- Mendel performed cross-pollination experiments to track which traits were produced by specific parental crosses.
- Mendel found that two genetic factors—one from a sperm cell and one from an egg cell—control each trait.
- **Dominant** traits block the expression of **recessive** traits. Recessive traits are expressed only when two recessive factors are present.

**Lesson 2: Understanding Inheritance**
- **Phenotype** describes how a trait appears.
- **Genotype** describes alleles that control a trait.
- **Punnett squares** and pedigrees are tools to model patterns of inheritance.
- Many patterns of inheritance, such as **codominance** and **polygenic inheritance**, are more complex than Mendel described.

**Lesson 3: DNA and Genetics**
- **DNA** contains an organism's genetic information.
- **RNA** carries the codes for making proteins from the nucleus to the cytoplasm. RNA also forms part of ribosomes.
- A change in the sequence of DNA, called a **mutation**, can change the traits of an organism.

### Vocabulary

<table>
<thead>
<tr>
<th>Heredity</th>
<th>Genetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominant</td>
<td>Recessive</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gene</th>
<th>Allele</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenotype</td>
<td>Genotype</td>
</tr>
<tr>
<td>Homozygous</td>
<td>Heterozygous</td>
</tr>
<tr>
<td>Punnett square</td>
<td>Incomplete dominance</td>
</tr>
<tr>
<td>Codominance</td>
<td>Polygenic inheritance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DNA</th>
<th>Nucleotide</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>Translation</td>
</tr>
<tr>
<td>RNA</td>
<td></td>
</tr>
</tbody>
</table>

Inherited genes are the basis of an organism's traits.
Chapter Project

Assemble your lesson Foldables as shown to make a Chapter Project. Use the project to review what you have learned in this chapter.

Link Vocabulary and Key Concepts

Copy this concept map, and then use vocabulary terms from the previous page to complete the concept map.

Use Vocabulary

1. The study of how traits are passed from parents to offspring is called ________.
2. The passing of traits from parents to offspring is ________.
3. Human height, weight, and skin color are examples of characteristics determined by ________.
4. A helpful device for predicting the ratios of possible genotypes is a(n) ________.
5. The code for a protein is called a(n) ________.
6. An error made during the copying of DNA is called a(n) ________.

7. An organism’s traits are passed from parent to offspring, which is called ________.
8. Factors are controlled by ________.
9. Factors are determined by information stored in ________.
10. Which can be modeled by ________.
11. Patterns of inheritance follow ________.
12. Which can be complex such as ________.
13. Stores instructions for making proteins that are produced by ________.
14. Can be altered, resulting in ________.
Understand Key Concepts

1. The process shown below was used by Mendel during his experiments.

What is the process called?
A. cross-pollination
B. segregation
C. asexual reproduction
D. blending inheritance

2. Which statement best describes Mendel’s experiments?
A. He began with hybrid plants.
B. He controlled pollination.
C. He observed only one generation.
D. He used plants that reproduce slowly.

3. Before Mendel’s discoveries, which statement describes how people believed traits were inherited?
A. Parental traits blend like colors of paint to produce offspring.
B. Parental traits have no effect on their offspring.
C. Traits from only the female parent are inherited by offspring.
D. Traits from only the male parent are inherited by offspring.

4. Which term describes the offspring of a first-generation cross between parents with different forms of a trait?
A. genotype
B. hybrid
C. phenotype
D. true-breeding

5. Which process makes a copy of a DNA molecule?
A. mutation
B. replication
C. transcription
D. translation

6. Which process uses the code on an RNA molecule to make a protein?
A. mutation
B. replication
C. transcription
D. translation

7. The Punnett square below shows a cross between a pea plant with yellow seeds and a pea plant with green seeds.

If mating produces 100 offspring, about how many will have yellow seeds?
A. 25
B. 50
C. 75
D. 100

8. Which term describes multiple genes affecting the phenotype of one trait?
A. codominance
B. blending inheritance
C. incomplete dominance
D. polygenic inheritance
Critical Thinking

9 Compare heterozygous genotype and homozygous genotype.

10 Distinguish between multiple alleles and polygenic inheritance.

11 Give an example of how the environment can affect an organism’s phenotype.

12 Predict In pea plants, the allele for smooth pods is dominant to the allele for bumpy pods. Predict the genotype of a plant with bumpy pods. Can you predict the genotype of a plant with smooth pods? Explain.

13 Interpret Graphics In tomato plants, red fruit (R) is dominant to yellow fruit (r). Interpret the Punnett square below, which shows a cross between a heterozygous red plant and a yellow plant. Include the possible genotypes and corresponding phenotypes.

<table>
<thead>
<tr>
<th></th>
<th>R</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>r</td>
<td>Rr</td>
<td>rr</td>
</tr>
<tr>
<td>r</td>
<td>Rr</td>
<td>rr</td>
</tr>
</tbody>
</table>

14 Compare and contrast characteristics of replication, transcription, translation, and mutation. Which of these processes takes place only in the nucleus of a cell? Which can take place in both the nucleus and the cytoplasm? How do you know?

Writing in Science

15 Write a paragraph contrasting the blending theory of inheritance with the current theory of inheritance. Include a main idea, supporting details, and a concluding sentence.

16 How are traits passed from generation to generation? Explain how dominant and recessive alleles interact to determine the expression of traits.

17 The photo below shows an albino offspring from a non-albino mother. If albinism is a recessive trait, what are the possible genotypes of the mother, the father, and the offspring?

Math Skills

18 A cross between two heterozygous pea plants with yellow seeds produced 1,719 yellow seeds and 573 green seeds. What is the ratio of yellow to green seeds?

19 A cross between two heterozygous pea plants with smooth green pea pods produced 87 bumpy yellow pea pods, 261 smooth yellow pea pods, 261 bumpy green pea pods, and 783 smooth green pea pods. What is the ratio of bumpy yellow to smooth yellow to bumpy green to smooth green pea pods?

20 A jar contains three red, five green, two blue, and six yellow marbles. What is the ratio of red to green to blue to yellow marbles?
Multiple Choice

Use the diagram below to answer questions 1 and 2.

1 Which genotype belongs in the lower right square?
   A YY
   B Yy
   C yY
   D yy

2 What percentage of plants from this cross will produce yellow seeds?
   A 25 percent
   B 50 percent
   C 75 percent
   D 100 percent

3 When Mendel crossed a true-breeding plant with purple flowers and a true-breeding plant with white flowers, ALL offspring had purple flowers. This is because white flowers are
   A dominant.
   B heterozygous.
   C polygenic.
   D recessive.

4 Which process copies an organism’s DNA?
   A mutation
   B replication
   C transcription
   D translation

5 Based on the pedigree above, how many offspring from this cross had the recessive phenotype?
   A 1
   B 2
   C 3
   D 5

6 Which is NOT true of a hybrid?
   A It has one recessive allele.
   B It has pairs of chromosomes.
   C Its genotype is homozygous.
   D Its phenotype is dominant.

7 Alleles are different forms of a
   A chromosome.
   B gene.
   C nucleotide.
   D protein.

8 Which is true of an offspring with incomplete dominance?
   A Both alleles can be observed in its phenotype.
   B Every offspring shows the dominant phenotype.
   C Multiple genes determine its phenotype.
   D Offspring phenotype is a combination of the parents’ phenotypes.
Use the diagrams below to answer question 9.

**Before Replication**

**After Replication**

9. The diagrams above show a segment of DNA before and after replication. Which occurred during replication?
   - A) deletion
   - B) insertion
   - C) substitution
   - D) translation

10. Which human characteristic is controlled by polygenic inheritance?
    - A) blood type
    - B) earlobe position
    - C) eye color
    - D) thumb shape

11. Mendel crossed a true-breeding plant with round seeds and a true-breeding plant with wrinkled seeds. Which was true of every offspring of this cross?
    - A) They had the recessive phenotype.
    - B) They showed a combination of traits.
    - C) They were homozygous.
    - D) They were hybrid plants.

**Constructed Response**

Use the diagram below to answer questions 12 and 13.

12. Describe what is happening in the phase of translation shown in the diagram.

13. What are the three types of RNA in the diagram? How do these types work together during translation?

14. What is the importance of translation in your body?

15. Mendel began his experiments with true-breeding plants. Why was this important?

16. How did Mendel’s experimental methods help him develop his hypotheses on inheritance?

17. What environmental factors affect the phenotypes of organisms other than humans? Provide three examples from nature. What factor, other than genes, affects human phenotype? Give two examples. Why is knowledge of this non-genetic factor helpful?