**SECTION 6.1 | CHROMOSOMES AND MEIOSIS**

**Study Guide**

**KEY CONCEPT**
Gametes have half the number of chromosomes that body cells have.

**VOCABULARY**
- somatic cell
- autosome
- fertilization
- gamete
- sex chromosome
- diploid
- homologous chromosome
- sexual reproduction
- haploid
- meiosis

**MAIN IDEA:** You have body cells and gametes.

1. What are the two major groups of cell types in the human body?

2. Where are gametes located?

3. How many chromosomes are in a typical human body cell?

**MAIN IDEA:** Your cells have autosomes and sex chromosomes.
Fill in the concept map below to summarize what you know about chromosomes.

- 46 chromosomes in human body cells include half come from sex chromosomes include 22 homologous pairs

- consist of include include

4. 

5. 

6. 

7. 

8. 
9. What is the sex of a person with two X chromosomes?

10. Which chromosome carries the fewest number of genes?

MAIN IDEA:  Body cells are diploid; gametes are haploid.

11. What happens to the nuclei of the egg and sperm during fertilization?

12. What type of cells are haploid?

13. What is the haploid chromosome number in humans?

14. How many autosomes are present in each human gamete? How many sex chromosomes?

15. Complete the following table to summarize the differences between mitosis and meiosis. Use Figure 6.2 to help you.

<table>
<thead>
<tr>
<th>Mitosis</th>
<th>Meiosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Makes diploid cells</td>
<td>Makes genetically unique cells</td>
</tr>
<tr>
<td>Happens throughout lifetime</td>
<td>Involved in sexual reproduction</td>
</tr>
</tbody>
</table>

Vocabulary Check

16. What are homologous chromosomes?

17. The word *soma* means “body.” How does this relate to the meanings of *autosome* and *somatic cell*?
SECTION 6.1

CHROMOSOMES AND MEIOSIS

Power Notes

Somatic cells: 

Gametes: 

Identify the items in the karyotype and explain their characteristics.

1. Autosomes...

2. 

3. 

Diploid cell: 

Haploid cell: 

Mitosis: 

Meiosis: 

Copyright © McDougal Littell/Houghton Mifflin Company.
SECTION 6.1 CHROMOSOMES AND MEIOSIS

Reinforcement

KEY CONCEPT Gametes have half the number of chromosomes that body cells have.

Your body is made of two basic cell types. One basic type are somatic cells, also called body cells, which make up almost all of your tissues and organs. The second basic type are germ cells, which are located in your reproductive organs. They are the cells that will undergo meiosis and form gametes. Gametes are sex cells. They include eggs and sperm cells.

Each species has a characteristic number of chromosomes per cell. Body cells are diploid, which means that each cell has two copies of each chromosome, one from each parent. Gametes are haploid, which means that each cell has one copy of each chromosome. Gametes join together during fertilization, which is the actual fusion of egg and sperm, and restores the diploid number.

The diploid chromosome number in humans is 46. Your cells needs both copies of each chromosome to function properly. Each pair of chromosomes is called homologous. Homologous chromosomes are a pair of chromosomes that have the same overall appearance and carry the same genes. One comes from the mother, and one comes from the father. Thus, one chromosome from a pair of homologous chromosomes might carry a gene that codes for green eye color, while the other carries a gene that codes for brown eye color.

For reference, each pair of homologous chromosomes has been numbered, from largest to smallest. Chromosome pairs 1 through 22 are autosomes. Autosomes are chromosomes that contain genes for characteristics not directly related to sex. The two other chromosomes are sex chromosomes, chromosomes that directly control the development of sexual characteristics. In humans, a woman has two X chromosomes, and a man has an X and a Y chromosome. The Y chromosome is very small and carries few genes.

Meiosis is a form of nuclear division that reduces chromosome number from diploid to haploid. Each haploid cell produced by meiosis has 22 autosomes and 1 sex chromosome.

1. How do gametes differ from somatic cells?

2. The prefix homo- means “the same.” Explain how this meaning relates to the definition of homologous chromosomes.

3. How does meiosis relate to haploid cells? How does fertilization relate to diploid cells?
KEY CONCEPT
During meiosis, diploid cells undergo two cell divisions that result in haploid cells.

MAIN IDEA: Cells go through two rounds of division in meiosis.

1. After a chromosome is replicated, each half is called a ________________________.

2. Two chromosomes that are very similar and carry the same genes are called ________________________.

In the space below, sketch the phases of meiosis I and II and write the name of each phase below it. Use Figure 6.5 to help you.

Meiosis I

3. 
4. 
5. 
6. 

Meiosis II

7. 
8. 
9. 
10. 

11. During which phase do homologous chromosomes separate? ________________________

12. During which phase do sister chromatids separate? ________________________
MAIN IDEA: Haploid cells develop into mature gametes.

13. What does a sperm cell contribute to an embryo?

14. What does an egg contribute to an embryo?

15. Where are polar bodies made, in the male or in the female?

Complete the diagram of gametogenesis in the boxes below. Use Figure 6.6 to help you.

Vocabulary Check

16. Genesis comes from a Greek word that means “to be born.” How does this relate to the meaning of gametogenesis?

17. What is a polar body?
SECTION 6.2
PROCESS OF MEIOSIS

**Power Notes**

Homologous chromosomes:  
Sister chromatids:

---

**Meiosis I**

1.  
2.  
3.  
4.  

**Meiosis II**

5.  
6.  
7.  
8.
SECTION 6.2 PROCESS OF MEIOSIS

**Reinforcement**

**KEY CONCEPT** During meiosis, diploid cells undergo two cell divisions that result in haploid cells.

Meiosis occurs after a cell has already duplicated its DNA. Cells go through two rounds of cell division during meiosis. During the first round, meiosis I, homologous chromosomes separate from each other. During the second round, meiosis II, sister chromatids separate from each other. Meiosis produces genetically unique haploid cells that will go through more steps to form mature gametes.

Meiosis is a continuous process, but scientists have divided it into phases.

- **Prophase I:** The nuclear membrane breaks down, and the spindle fibers assemble. The duplicated chromosomes condense, and homologous chromosomes pair up. The sex chromosomes also pair together.
- **Metaphase I:** The homologous chromosome pairs randomly line up along the middle of the cell. Because this is random, there are a mixture of chromosomes from both parents on each side of the cell equator.
- **Anaphase I:** The paired homologous chromosomes separate from each other and move to opposite sides of the cell.
- **Telophase I:** The nuclear membrane forms in some species, the spindle fibers break apart, and the cell undergoes cytokinesis. Each cell has 23 duplicated chromosomes.
- **Prophase II:** The nuclear membrane breaks down if necessary and the spindle fibers assemble again.
- **Metaphase II:** The chromosomes line up along the middle of the cell.
- **Anaphase II:** The sister chromatids are pulled apart from each other and move to opposite sides of the cell.
- **Telophase II:** The nuclear membranes form again, the spindle fibers break apart, and the cell undergoes cytokinesis.

The haploid cells produced by meiosis are not capable of fertilization. They must undergo additional steps to form mature gametes. During **gametogenesis**, sperm cells—the male gametes—and eggs—the female gametes—become specialized to carry out their functions. Sperm cells lose much of their cytoplasm and develop a tail. Eggs receive almost all of the cytoplasm during the divisions in meiosis. This is necessary for an embryo to have all the materials needed to begin life after fertilization. The smaller cells produced by meiosis in the female are called **polar bodies**, and they are eventually broken down.

1. During which phase do homologous chromosomes separate?

2. During which phase do sister chromatids separate?
KEY CONCEPT

Mendel’s research showed that traits are inherited as discrete units.

VOCABULARY

<table>
<thead>
<tr>
<th>trait</th>
<th>purebred</th>
<th>law of segregation</th>
</tr>
</thead>
<tbody>
<tr>
<td>genetics</td>
<td>cross</td>
<td></td>
</tr>
</tbody>
</table>

MAIN IDEA: Mendel laid the groundwork for genetics.

1. What is genetics?

2. Whose early work is the basis for much of our current understanding of genetics?

3. How did Mendel’s views on inheritance differ from the views of many scientists of his time?

MAIN IDEA: Mendel’s data revealed patterns of inheritance.

In designing his experiments, Mendel made three important choices that helped him see patterns of inheritance. In the table below, list Mendel’s three choices and write an example of how he put each of these choices into action.

<table>
<thead>
<tr>
<th>Mendel’s Choices</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td></td>
</tr>
</tbody>
</table>

7. Why did Mendel use pea plants?
8. Fill in the sequence diagram below to summarize Mendel’s experimental process.

Bred flowers resulting in F₁ generation with dominant phenotype.

Resulted in F₂ generation with both dominant and recessive phenotypes.

9. Mendel concluded that traits are inherited as “discrete units.” What do we call these discrete units today?

10. What two conclusions make up Mendel’s law of segregation?

Vocabulary Check

11. Segregation means “separation.” What is “segregated” in Mendel’s law of segregation?

12. What does “purebred” mean?
Mendel's Experiments

Three key choices:

- 
- 
- 

Pea plant characteristics:

- 
- 
- 
- 
- 

Cross:

- P
- F₁
- F₂

Results:

Conclusions:

Law of segregation:

- 
-
SECTION 6.3 | MENDEL AND HEREDITY

Reinforcement

KEY CONCEPT Mendel’s research showed that traits are inherited as discrete units.

Traits are inherited characteristics, and genetics is the study of the biological inheritance of traits and variation. Gregor Mendel, an Austrian monk, first recognized that traits are inherited as discrete units. We call these units genes. Mendel conducted his experiments with pea plants, which were an excellent choice because they are easily manipulated, produce large numbers of offspring, and have a short life cycle. Mendel made three important decisions that helped him to see patterns in the resulting offspring.

- Use of purebred plants: Mendel used pea plants that had self-pollinated for so long that they had become genetically uniform, or purebred. This meant that the offspring looked like the parent plant. Because of this characteristic, Mendel knew that any differences he observed in the offspring were the result of his experiments.
- Control over breeding: At the start of his experiments, Mendel removed the male flower parts from the pea plants. He then pollinated the female flower part with pollen from a plant of his choosing, which produced offspring referred to as the F1 generation.
- Observation of “either-or” traits: Mendel studied seven traits that appeared in only two forms. For example, flowers were white or purple; peas were wrinkled or round.

Mendel observed that when he mated, or crossed, a purple-flowered plant with a white-flowered plant, for example, all of the F1 offspring had purple flowers. Mendel next allowed the F1 offspring to self-pollinate; that is, the plant mated with itself. In the resulting offspring, the F2 generation, approximately three-fourths of the flowers were purple and one-fourth were white. Mendel continued to find this 3:1 ratio for each of his crosses, regardless of the specific trait he was examining.

Based on his results, Mendel concluded that traits are inherited as discrete units. He also developed what is known as Mendel’s first law, or the law of segregation. This law states the following:

- Organisms inherit two copies of each unit (gene), one from each parent.
- The two copies separate, or segregate, during gamete formation. As a result, organisms donate only one copy of each unit (gene) in their gametes.

1. In which generation of offspring did Mendel observe a 3:1 ratio in the appearance of the offspring?

2. What is segregating in the law of segregation? When does this segregation occur?
SECTION 6.4 TRAITS, GENES, AND ALLELES

Study Guide

KEY CONCEPT

Genes encode proteins that produce a diverse range of traits.

VOCABULARY

<table>
<thead>
<tr>
<th>term</th>
<th>gene</th>
<th>heterozygous</th>
<th>phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>allele</td>
<td>genome</td>
<td></td>
<td>dominant</td>
</tr>
<tr>
<td>homozygous</td>
<td>genotype</td>
<td>recessive</td>
<td></td>
</tr>
</tbody>
</table>

MAIN IDEA: The same gene can have many versions.

1. What is the relationship between a gene and a protein?

2. What is an allele?

3. What term describes a pair of alleles that are the same? that are different?

4. Write a definition of homologous chromosomes using the terms “gene” and “allele.”

In the space below, draw a pair of homologous chromosomes. Label the chromosomes with two sets of genes, one with homozygous alleles (Gene A, Gene A) and one with heterozygous alleles (Gene B, Gene b).
STUDY GUIDE, CONTINUED

MAIN IDEA: Genes influence the development of traits.

5. Write an analogy to show the difference between genotype and phenotype.

6. How are alleles represented on paper?

7. Fill in the table below with the missing genotype, phenotype (dominant or recessive), or alleles (TT, Tt, tt).

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
<th>Alleles</th>
</tr>
</thead>
<tbody>
<tr>
<td>homozygous dominant</td>
<td>recessive</td>
<td>Tt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8. If an organism has a recessive trait, can you determine its genotype for that trait?

9. What factors besides alleles affect phenotype?

Vocabulary Check

10. What type of alleles are present in an organism with a QQ genotype?

11. What is an alternative form of a gene?

12. What is the opposite of homozygous? of dominant?
SECTION 6.4

TRAITS, GENES, AND ALLELES

Power Notes

Gene:

Allele:

Genome:

Symbols:

Genotype:

Dominant:

Homozygous:

Recessive:

Heterozygous:

Phenotype:
KEY CONCEPT  Genes encode proteins that produce a diverse range of traits.

A gene is a segment of DNA that tells the cell how to make a particular polypeptide. The location of a gene on a chromosome is called a locus. A gene has the same locus on both chromosomes in a pair of homologous chromosomes. In genetics, scientists often focus on a single gene or set of genes. **Genotype** typically refers to the genetic makeup of a particular set of genes. **Phenotype** refers to the physical characteristics resulting from those genes.

An alternative form of a gene is an allele. The pea plants that Mendel worked with had two alleles for each gene. For example, there was an allele for round peas and an allele for wrinkled peas. Genes are not limited to two alleles, however. Some genes are found in many different forms throughout a population.

Your cells have two alleles for each gene regardless of how many alleles are present in a population. Suppose there were 64 alleles of a hair color gene present in the human population. Your cells would only have two of those alleles, one from your mother and one from your father. If the two alleles are the same, they are **homozygous**. If the two alleles are different, they are **heterozygous**.

Some alleles are dominant over others.
- A **dominant** allele is expressed when two different alleles or two dominant alleles are present. Therefore, both homozygous dominant and heterozygous genotypes can produce the dominant phenotype.
- A **recessive** allele is expressed only when both alleles are recessive. Therefore, only the homozygous recessive genotype can produce the recessive phenotype.

Alleles may be represented using letters. Uppercase letters represent dominant alleles. Lowercase letters represent recessive alleles.

1. If you were to make an analogy and say that genotype is like blueprints, how would you complete the analogy to describe phenotype?

2. Use the letters B and b to represent the following genotypes: heterozygous, homozygous recessive, homozygous dominant.
### KEY CONCEPT

The inheritance of traits follows the rules of probability.

### VOCABULARY

<table>
<thead>
<tr>
<th>Punnett square</th>
<th>testcross</th>
<th>law of independent assortment</th>
</tr>
</thead>
<tbody>
<tr>
<td>monohybrid cross</td>
<td>dihybrid cross</td>
<td>probability</td>
</tr>
</tbody>
</table>

### MAIN IDEA: Punnett squares illustrate genetic crosses.

Identify what each of the numbered parts represents in the Punnett square below. Then draw lines from each of the parents’ alleles to the corresponding alleles in the offspring.

1. 

2. 

3. 

4. Why does each parent contribute only one allele to the offspring?

### MAIN IDEA: A monohybrid cross involves one trait.

5. You know a ratio is a comparison that tells how two or more things relate. What is a genotypic ratio? a phenotypic ratio?

6. What is the genotypic ratio of the offspring in Figure 6.15?

7. What is the phenotypic ratio of the offspring in Figure 6.15?
MAIN IDEA: A dihybrid cross involves two traits.

8. What is a dihybrid cross?

9. Why does each parent organism in the F1 generation have four alleles listed in Figure 6.17?

10. Suppose an organism had the genotype AABb. What two types of gametes could result from this allele combination?

11. What is the phenotypic ratio that results from a dihybrid cross between two organisms that are heterozygous for both traits? See Figure 6.17 for help.

MAIN IDEA: Heredity patterns can be calculated with probability.

12. Probability predicts the number of occurrences, not the number of occurrences.

13. To calculate the probability that two independent events will happen together, the probability of each individual event.

14. In Figure 6.18, the probability of getting one coin that is heads up and one coin that is tails up is .

Vocabulary Check

15. What is a testcross?

16. What is independent in the law of independent assortment?
SECTION 6.5 | TRAITS AND PROBABILITY

Punnett Square
- Axes:
- Grid boxes:

Ratios:
- 
- 

Testcross:

Monohybrid cross:

Dihybrid cross:

Ratios:
- 
- 

Law of independent assortment:

Probability:
SECTION 6.5 | TRAITS AND PROBABILITY

Reinforcement

KEY CONCEPT  The inheritance of traits follows the rules of probability.

The possible genotypes resulting from a cross can be predicted using a Punnett square. A **Punnett square** is a grid. The axes are labeled with the alleles of each parent organism. The grid boxes show all of the possible genotypes of the offspring resulting from those two parents.

A **monohybrid cross** is used when studying only one trait. A cross between a homozygous dominant organism and a homozygous recessive organism produces offspring that are all heterozygous and have the dominant phenotype. A cross between two heterozygous organisms results in a 3:1 phenotypic ratio in the offspring, where three-fourths have the dominant phenotype and one-fourth have the recessive phenotype. The genotypic ratio resulting from this cross is 1:2:1 of homozygous dominant:heterozygous:homozygous recessive.

A **testcross** is a cross between an organism with an unknown genotype (dominant phenotype) and an organism with the recessive phenotype. If the organism with the unknown genotype is homozygous dominant, the offspring will all have the dominant phenotype. If it is heterozygous, half the offspring will have the dominant phenotype, and half will have the recessive phenotype.

A **dihybrid cross** is used when studying the inheritance of two traits. Mendel’s dihybrid crosses helped him develop the **law of independent assortment**, which basically states that different traits are inherited separately. When two organisms that are heterozygous for both traits are crossed, the resulting phenotypic ratio is 9:3:3:1.

**Probability** is the likelihood that a particular event, such as the inheritance of a particular allele, will happen. The events of meiosis and fertilization are random, so hereditary patterns can be calculated with probability.

On a separate sheet of paper, draw a Punnett square for a cross between organisms that have the genotypes Bb and bb. Use the Punnett square to answer the following questions.

1. Is this a monohybrid cross or a dihybrid cross?

2. What is the genotypic ratio of the offspring?

3. What is the phenotypic ratio of the offspring?
KEY CONCEPT
Independent assortment and crossing over during meiosis result in genetic diversity.

MAIN IDEA: Sexual reproduction creates unique gene combinations.
1. What are two ways that sexual reproduction helps create and maintain genetic diversity?

2. Which does sexual reproduction create, new alleles or new combinations of alleles?

3. How is the production of unique genetic combinations an advantage to organisms and species?

MAIN IDEA: Crossing over during meiosis increases genetic diversity.
4. Are chromosomes in a duplicated or an unduplicated state when crossing over occurs?

Use sketches to illustrate how crossing over contributes to genetic diversity. Use Figure 6.20 for reference.
1. Draw a cell with four chromosomes in the first box. Make one pair of chromosomes large and the other pair small. Color in one large chromosome and one small chromosome. Leave the other two chromosomes white.
2. In the next box, draw the cell in prophase I. Have each pair of homologous chromosomes line up together—large with large, small with small.
3. In the third box, show crossing over between each pair of homologous chromosomes.
4. In the last box, show what the chromosomes look like as a result of crossing over. You will use this sketch in the next exercise.
Refer to your cell sketch in the last box on the previous page. Also refer to Figure 6.5 if necessary. 1. In the first box below, show what your cell would look like at the end of meiosis I. Remember, the result will be two cells that have one duplicated chromosome from each homologous pair. 2. In the second box, show what your cell would look like at the end of meiosis II. Remember, the result will be four cells that have one (unduplicated) chromosome from each homologous pair.

5. If genes A and B are located on separate, nonhomologous chromosomes, will they follow Mendel’s law of independent assortment? Explain.

6. If genes A and B are located at opposite ends on the same chromosome, are they likely to follow Mendel’s law of independent assortment? Explain.

7. If genes A and B are located very close together on the same chromosome, are they likely to follow Mendel’s law of independent assortment? Explain.

**Vocabulary Check**

8. The exchange of chromosome segments between homologous chromosomes is called ______________________.

9. The tendency for two genes that are located close together on a chromosome to be inherited together is called ______________________.
Genetic Diversity

- Fertilization:

- Meiosis:

- Crossing over:

Fill in the final box to illustrate crossing over.

Genetic linkage:
KEY CONCEPT Independent assortment and crossing over during meiosis result in genetic diversity.

In organisms that reproduce sexually, the independent assortment of chromosomes during meiosis and the random fertilization of gametes creates a lot of new genetic combinations. In humans, for example, there are over 64 trillion different possible combinations of chromosomes. Sexual reproduction creates genetically unique offspring that have a combination of both parents’ traits. This uniqueness increases the likelihood that some organisms will survive or even flourish in changing conditions.

Genetic diversity is further increased through crossing over. **Crossing over** is the exchange of segments of chromosomes between homologous chromosomes. It happens during prophase I of meiosis I when homologous chromosomes pair up with each other and come into very close contact. At this stage, the chromosomes have already been duplicated. Part of a chromatid from each homologous chromosome may break off and reattach to the other chromosome.

Crossing over is more likely to occur between genes that are far apart from each other on a chromosome. The likelihood that crossing over will happen is much less if two genes are located close together. Thus, genes that are located close together on a chromosome have a tendency to be inherited together, which is called **genetic linkage**. Most of the traits that Mendel studied were located on separate chromosomes, and so they assorted independently. When genes are on the same chromosome, however, their distance from each other is a large factor in how they assort. If they are far apart, crossing over is likely to occur between them and so they will assort independently. If they are close together, they are unlikely to be separated by crossing over and so they will not assort independently.

1. What factors contribute to genetic diversity?

2. What is crossing over?

3. If two genes are located close together on the same chromosome, are they likely to follow Mendel’s law of independent assortment? Explain.
Bar graphs represent data using bars to show data points.

In the example below, students collected data about the natural hair color of 200 students, faculty, and staff at their school. The bar graph shows the results of their survey.

**GRAPH 1. HAIR COLOR SURVEY**

1. **Analyze** Which hair color was the most common? Which was the least common?

2. **Hypothesize** Based on the observations made by the students, form a testable hypothesis about how hair color is inherited.
In Chapter 6, you have learned about Gregor Mendel and his research with garden peas. Mendel published his paper, “Versuche über Pflanzen Hybriden” (Experiments in Plant Hybridization), in 1865. Remember that he made his conclusions at a time when DNA, genes, and chromosomes were unknown. How can Mendel’s conclusions be interpreted today?

The following excerpts taken from Mendel’s paper deal with his observations of different generations of pea plants. Read each excerpt, then write an interpretation of each using the modern principles and terms you have learned. (Note: Mendel used italics for emphasis.) Here is an example:

In this [F2] generation there reappear, together with the dominant characters, the recessive ones with their peculiarities fully developed, and this occurs in the definitely expressed average proportion of three to one, so that among each four plants of this generation three display the dominant character and one the recessive . . . Transitional forms were not observed in any experiment.

Interpretation: When you cross two plants that are heterozygous for dominant-recessive traits, the ratio of phenotypes among the offspring is 3 dominant to 1 recessive. Simple dominant-recessive traits are inherited as discrete units and do not blend together.

As you work on your interpretations of the following excerpts, you might want to make a note of the meanings of specific terms Mendel uses, such as forms, character, hybrid, egg cell, pollen cell, classes, and conjoined.

1. “Those forms which in the first generation exhibit the recessive character do not further vary in the second generation as regards this character; they remain constant in their offspring.”

2. “Experimentally, therefore, the theory is confirmed that the pea hybrids form egg and pollen cells which, in their constitution, represent in equal numbers all constant forms which result from the combination of the characters united in fertilization.”
3. When referring to the cross between two hybrid plants, Mendel wrote “The simplest case is afforded by the developmental series of each pair of differentiating characters. This series is represented by the expression $A + 2Aa + a$, in which $A$ and $a$ signify the forms with constant differentiating characters, and $Aa$ the hybrid form of both. It includes in three different classes four individuals. In the formation of these, pollen and egg cells of the form $A$ and $a$ take part on the average equally in the fertilization; hence each form [occurs] twice, since four individuals are formed. They participate consequently in the fertilization:

pollen cells $A + A + a + a$  +  egg cells $A + A + a + a$

It remains, therefore, purely a matter of chance which of the two sorts of pollen will become united with each separate egg cell.”

4. “The result of the fertilization may be made clear by putting the signs of the conjoined egg and pollen cells in the form of fractions, those for the pollen cells above and those for the egg cells below the line. We then have $A/A + A/a + a/A + a/a$.”

5. When summarizing the results of crosses between plants that differed in two or three characters, Mendel wrote “It is demonstrated at the same time that the relation of each pair of different characters in hybrid union is independent of the other differences in the two original parental stocks.”
In Chapter 6 you have learned about the probabilities expected in the offspring of genetic crosses. Here you will use a chi square test to see how much Mendel’s results agreed with his expected results and hypothesis.

**PROBABILITY**

You can use Punnett squares to determine the possible outcomes of a genetic cross and to find the probabilities of each outcome. For example, in a monohybrid cross between two heterozygous round-seeded plants, two phenotypes—round seeds and wrinkled-seeds—have probabilities 3 out of 4 (3/4) and 1 out of 4 (1/4), respectively. Mendel observed the seed shapes of 7324 plants. If his observed results agreed exactly with his hypothesis, 75%, or 5493, of the offspring plants would have had round seeds. But in fact, Mendel saw 5474 plants with round seeds. Probabilities predict but do not guarantee the outcomes of experiments. If chance plays a role, how can we know that Mendel’s actual results were not achieved by blind luck?

**THE CHI SQUARE TEST**

The chi square test offers a way to determine if differences between the expected and actual results of an experiment are due to chance. The chi square test is basically an equation whose outcome shows if an experiment’s results are within 5% of the expected results. The variables that are plugged into this equation are as follows:

- \( K \) = The number of possible outcomes that can be observed in an experiment. In flipping a coin, \( K \) is 2 (heads and tails). \( K \) is 2 for the possible phenotypes resulting from a monohybrid cross (dominant and recessive). In Mendel’s dihybrid cross, \( K \) is 4 (wrinkled-yellow, wrinkled-green, round-green, round-yellow).
- \( N \) = The number of observations or results. For example, Mendel’s monohybrid pea plant cross yielded 7324 plants, so \( N = 7324 \).
- \( E \) = The number of times you expect a specific outcome. This is determined by multiplying the probability of an outcome by \( N \).

In Mendel’s cross, the dominant phenotype is assigned outcome 1 or \( K(1) \). The recessive phenotype = outcome 2 or \( K(2) \). Therefore, each \( N \) is labeled \( N(1) \), \( N(2) \), and so on, all the way up through \( N(K) \). In Mendel’s cross, \( N(1) = 5474 \) and \( N(2) = 1850 \).

Each outcome, or \( K \), has an expected probability: \( P(1) \), \( P(2) \), and so on, up through \( P(K) \). For a monohybrid cross, \( P(1) \) is 3/4, and \( P(2) \) is 1/4. From \( P \) we get \( E \) by multiplying it by \( N \). So, \( E(1) = N \times P(1) \), \( E(2) = N \times P(2) \), and so on. In general, \( E(K) = N \times P(K) \).

The chi square equation is as follows:

\[
\chi^2 = \frac{[N(1) - E(1)]^2}{E(1)} + \frac{[N(2) - E(2)]^2}{E(2)} + \ldots + \frac{[N(K) - E(K)]^2}{E(K)}
\]

You square the difference between the expected result and observed result for a specific outcome, and divide that by the expected result. This yields a ratio. Do this for all of the...
possible outcomes, and then add up all of the ratios. (The more possible outcomes \(K\), the more ratios you have to add up.) The resulting sum, or \(\chi^2\), has a known probability distribution, called the chi squared distribution. There is a different chi squared distribution for each value of \(K\), or number of possible outcomes. Scientists say that data are significantly different from the hypothesis if the chance of seeing a value of \(\chi^2\) larger than the one that you calculated is 5% or less. To apply this rule, scientists check whether \(\chi^2\) exceeds a constant called the critical value. Below is a table of critical values.

<table>
<thead>
<tr>
<th>(K)</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
</table>

Applying the expected and actual results from Mendel’s monohybrid cross to the chi square formula gives us

\[
\chi^2 = \frac{(5474 - 5493)^2}{5493} + \frac{(1850 - 1831)^2}{1831} = \frac{361}{5493} + \frac{361}{1831} = 0.066 + 0.197 = 0.263
\]

Since the calculated value of 0.263 is less than the critical value of 3.84, you can conclude that the data and the hypothesis do not contradict one another, and the similarity between Mendel’s expected and actual results is not a coincidence or stroke of luck.

Answer the following questions on a separate sheet of paper.

1. Mendel hypothesized that the four phenotypes of a dihybrid cross should appear in the ratio of 9:3:3:1. The table below gives the number of times each phenotype appeared out of 556 plants. Convert Mendel’s expected ratio of the four phenotypes into probabilities of each. Calculate the expected number—\(E(1), E(2), E(3), E(4)\)—of each outcome (remember: \(N = 556\)). Record your answers in the table. Round \(N\) values to the nearest whole number.

<table>
<thead>
<tr>
<th>Phenotype ((K))</th>
<th>round &amp; yellow ((1))</th>
<th>wrinkled &amp; yellow ((2))</th>
<th>round &amp; green ((3))</th>
<th>wrinkled &amp; green ((4))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N(K))</td>
<td>315</td>
<td>101</td>
<td>108</td>
<td>32</td>
</tr>
<tr>
<td>(P(K))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(E(K))</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Calculate the \(\chi^2\) from the data. Round decimals to the nearest thousandth throughout your calculation. Show your complete calculation with variables in place. Are Mendel’s results significant? Explain.
# Vocabulary Practice

<table>
<thead>
<tr>
<th><strong>somatic cell</strong></th>
<th><strong>egg</strong></th>
<th><strong>genotype</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>gamete</strong></td>
<td><strong>polar body</strong></td>
<td><strong>phenotype</strong></td>
</tr>
<tr>
<td><strong>homologous chromosome</strong></td>
<td><strong>trait</strong></td>
<td><strong>dominant</strong></td>
</tr>
<tr>
<td><strong>autosome</strong></td>
<td><strong>genetics</strong></td>
<td><strong>recessive</strong></td>
</tr>
<tr>
<td><strong>sex chromosome</strong></td>
<td><strong>purebred</strong></td>
<td><strong>Punnett square</strong></td>
</tr>
<tr>
<td><strong>sexual reproduction</strong></td>
<td><strong>cross</strong></td>
<td><strong>monohybrid cross</strong></td>
</tr>
<tr>
<td><strong>fertilization</strong></td>
<td><strong>law of segregation</strong></td>
<td><strong>testcross</strong></td>
</tr>
<tr>
<td><strong>diploid</strong></td>
<td><strong>gene</strong></td>
<td><strong>dihybrid cross</strong></td>
</tr>
<tr>
<td><strong>haploid</strong></td>
<td><strong>allele</strong></td>
<td><strong>law of independent assortment</strong></td>
</tr>
<tr>
<td><strong>meiosis</strong></td>
<td><strong>homozygous</strong></td>
<td><strong>probability</strong></td>
</tr>
<tr>
<td><strong>gametogenesis</strong></td>
<td><strong>heterozygous</strong></td>
<td><strong>crossing over</strong></td>
</tr>
<tr>
<td><strong>sperm</strong></td>
<td><strong>genome</strong></td>
<td><strong>genetic linkage</strong></td>
</tr>
</tbody>
</table>

## A. Situational Vocabulary

Circle the letter of the situation that most closely relates to each vocabulary word.

1. **fertilization**: a) union of gametes; b) division of chromosomes
2. **purebred**: a) a scruffy mutt; b) a sleek Labrador retriever
3. **diploid**: a) a dollar; b) fifty cents
4. **sexual reproduction**: a) produces genetically identical offspring; b) produces genetically unique offspring
5. **trait**: a) inheriting your father’s laugh; b) inheriting your father’s watch
6. **homologous chromosomes**: a) carry the same genes; b) carry identical alleles
7. **Punnett square**: a) like playing tic-tac-toe; b) like playing rock-paper-scissors
8. **genome**: a) like a computer hard drive; b) like a computer screen
9. **polar body**: a) becomes a baby; b) becomes broken down by the body
10. **meiosis**: a) preserves chromosome number; b) reduces chromosome number
11. **testcross**: a) reveals phenotype; b) reveals genotype
12. **probability**: a) the likelihood a given event will occur; b) the number of times a given event has occurred
**B. The Same But Different** For each pair of words listed in the table below, list one way that they are similar and one way that they are different.

<table>
<thead>
<tr>
<th>SIMILARITY</th>
<th>WORD PAIRS</th>
<th>DIFFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>laws of genetics developed by Mendel</td>
<td>law of segregation</td>
<td>organisms have two copies of every gene but donate only one</td>
</tr>
<tr>
<td>law of independent assortment</td>
<td>characteristics are inherited independently of each other</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>autosome</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sex chromosome</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>somatic cell</td>
<td></td>
</tr>
<tr>
<td></td>
<td>gamete</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>sperm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>egg</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>homozygous</td>
<td></td>
</tr>
<tr>
<td></td>
<td>heterozygous</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>dominant</td>
<td></td>
</tr>
<tr>
<td></td>
<td>recessive</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>diploid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>haploid</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>monohybrid cross</td>
<td></td>
</tr>
<tr>
<td></td>
<td>dihybrid cross</td>
<td></td>
</tr>
</tbody>
</table>
Gregor Mendel wanted to understand how ____________ were inherited, so he performed ____________ experiments using pea plants. Mendel used plants that were ____________, which means that the plants had self-pollinated for so long that the offspring always looked like the parent plant. He examined seven “either-or” characteristics. First, Mendel ____________ a plant displaying the dominant phenotype with a plant displaying the recessive phenotype. Next, he allowed the offspring of this cross, the F₁ generation, to self-pollinate, and then calculated the phenotypic ratios that he observed in the F₂ offspring.

From his monohybrid crosses, Mendel developed his first law, the ____________. This law states that each parent organism has two copies of each discrete unit, or ____________, and that the two copies separate from each other during ____________. Mendel then performed dihybrid crosses, and as a result, developed his second law, the ____________. This law states essentially that the inheritance of one trait does not influence the inheritance of another trait. Mendel’s second law applies to genes that are on separate chromosomes or to genes that are so far apart on the same chromosome that they have a strong chance of being separated by ____________. However, his second law does not apply to genes that exhibit ____________ because they are close together on the same chromosome.
D. Vector Vocabulary  Define the words in the boxes. On the line across each arrow, write a phrase that describes how the words in the boxes are related to each other.

**GENE**
1. __________________________
   __________________________
2. __________________________

**PHENOTYPE**
5. __________________________
   __________________________
4. __________________________

**allelle**
3. __________________________

**DOMINANT**
7. __________________________
   __________________________

**RECESSIVE**
8. __________________________
   __________________________

**HOMOZYGOUS**
12. __________________________
    __________________________

**HETEROZYGOUS**
13. __________________________