Unit 4

History & Biology

1800 1850

1863 Lincoln writes the Emancipation Proclamation.

1865 Mendel discovers the rules of inheritance.

Genetics

What You'll Learn

Chapter 10
Mendel and Meiosis

Chapter 11
DNA and Genes

Chapter 12
Patterns of Heredity and Human Genetics

Chapter 13
Genetic Technology

Unit 4 Review
BioDigest & Standardized Test Practice

Why It's Important

Physical traits, such as the stripes of these tigers, are encoded in small segments of a chromosome called genes, which are passed from one generation to the next. By studying the inheritance pattern of a trait through several generations, the probability that future offspring will express that trait can be predicted.

California Standards

The following standards are covered in Unit 4:
Investigation and Experimentation: 1a, 1d, 1i, 1j, 1k, 1m
Biology/Life Sciences: 2a, 2b, 2c, 2d, 2e, 3, 3a, 3b, 3c, 3d, 4a, 4b, 4c, 5a, 5b, 5c, 5d, 5e, 7b, 7c

Understanding the Photo

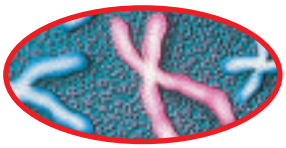
White tigers differ from orange tigers by having ice-blue eyes, a pink nose, and creamy white fur with brown or black stripes. They are not albinos. The only time a white tiger is born is when its parents each carry the white-coloring gene. White tigers are very rare, and today, they are only seen in zoos.

1950 The Korean War begins when North Korea invades South Korea.

1964 The Beatles make their first appearance on American TV.

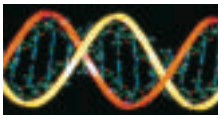
1900 1950 2000

1910 Scientists determine that genes reside on chromosomes.



1944 Scientists suggest genetic material is DNA, not protein. The results are not accepted.

1952 Alfred Hershey and Martha Chase show conclusively that DNA is the genetic material.



1953 Watson, Crick, Wilkins, and Franklin determine the structure of DNA.

1961 The genetic code is cracked.

1990 The Human Genome Project begins to map and sequence the entire human genome.

2000 Most of the human DNA sequence is completed.

(tl)Omikron/Science Source/Photo Researchers, (tr)CNRI/Phototake, NYC

Chapter 10

Mendel and Meiosis

What You'll Learn

- You will identify the basic concepts of genetics.
- You will examine the process of meiosis.

Why It's Important

Genetics explains why you have inherited certain traits from your parents. If you understand how meiosis occurs, you can see how these traits were passed on to you.

Understanding the Photo

Zebras usually travel in large groups, and each zebra's stripes blend in with the stripes of the zebras around it. This confuses predators. Rather than seeing individual zebras, predators see a large, striped mass. Zebra stripe patterns are like human fingerprints—they are genetically determined, and every zebra's stripe pattern is unique.

Biology Online

Visit ca.bdol.glencoe.com to

- study the entire chapter online
- access Web Links for more information and activities on genetics and meiosis
- review content with the Interactive Tutor and self-check quizzes

Dr. G.G. Dimijian/Photo Researchers

CONTENTS

Section 10.1

Mendel's Laws of Heredity

California Standards Standard 3b Students know the genetic basis for Mendel's laws of segregation and independent assortment.

SECTION PREVIEW

Objectives

Relate Mendel's two laws to the results he obtained in his experiments with garden peas.

Predict the possible offspring of a genetic cross by using a Punnett square.

Review Vocabulary

experiment: a procedure that tests a hypothesis by the process of collecting data under controlled conditions (p. 13)

New Vocabulary

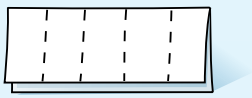
heredity
trait
genetics
gamete
fertilization
zygote
pollination
hybrid
allele
dominant
recessive
law of segregation
phenotype
genotype
homozygous
heterozygous
law of independent assortment

FOLDABLES™ Study Organizer

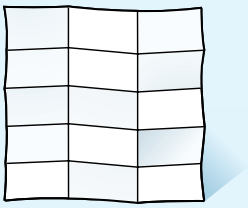
Heredity Make the following Foldable to help you organize information about Mendel's laws of heredity.

STEP 1 **Fold** one piece of paper lengthwise into thirds.

STEP 2 **Fold** the paper widthwise into fifths.



STEP 3 **Unfold,** lay the paper lengthwise, and draw lines along the folds.



STEP 4 **Label** your table as shown.

Mendel	Describe in Your Words	Give an Example
Rule of unit factors		
Rule of dominance		
Law of segregation		
Law of independent assortment		

Make a Table As you read Chapter 10, complete the table describing Mendel's rules and laws of heredity.

Why Mendel Succeeded

People have noticed for thousands of years that family resemblances are inherited from generation to generation. However, it was not until the mid-nineteenth century that Gregor Mendel, an Austrian monk, carried out important studies of **heredity**—the passing on of characteristics from parents to offspring. Characteristics that are inherited are called **traits.** Mendel was the first person to succeed in predicting how traits are transferred from one generation to the next. A complete explanation requires the careful study of **genetics**—the branch of biology that studies heredity.

Word Origin

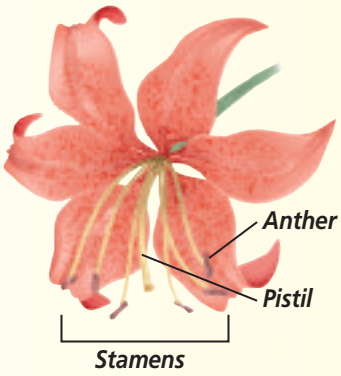
heredity from the Latin word *hered-*, meaning "heir"; Heredity describes the way the genetic qualities you receive from your ancestors are passed on.

Mendel chose his subject carefully

Mendel chose to use the garden pea in his experiments for several reasons. Garden pea plants reproduce sexually, which means that they produce male and female sex cells, called **gametes.** The male gamete forms in the pollen grain, which is produced in the male reproductive organ. The female gamete forms in the female reproductive organ. In a process called **fertilization,** the male gamete unites with the female gamete. The resulting fertilized cell, called a **zygote** (ZI goht), then develops into a seed.

MiniLab 10.1

Observe and Infer



Looking at Pollen Pollen grains are formed within the male anthers of flowers. What is their role? Pollen contains the male gametes, or sperm cells, needed for fertilization. This means that pollen grains carry the hereditary units from male parent plants to female parent plants. The pollen grains that Mendel transferred from the anther of one pea plant to the female pistil of another plant carried the hereditary traits that he so carefully observed in the next generation.

Procedure

1. Examine a flower. Using the diagram as a guide, locate the stamens of your flower. There are usually several stamens in each flower.
2. Remove one stamen and locate the enlarged end—the anther.
3. Add a drop of water to a microscope glass slide. Place the anther in the water. Add a coverslip. Using the eraser end of a pencil, tap the coverslip several times to squash the anther.
4. Observe under low power. Look for numerous small round structures. These are pollen grains.

Analysis

1. **Estimate** Provide an estimate of the number of pollen grains present in an anther.
2. **Describe** What does a single pollen grain look like?
3. **Explain** What is the role of pollen grains in plant reproduction?

The transfer of pollen grains from a male reproductive organ to a female reproductive organ in a plant is called **pollination.** In peas, both organs are located in the same flower and are tightly enclosed by petals. This prevents pollen from other flowers from entering the pea flower. As a result, peas normally reproduce by self-pollination; that is, the male and female gametes come from the same plant. In many of Mendel's experiments, this is exactly what he wanted. When he wanted to breed, or cross, one plant with another, Mendel opened the petals of a flower and removed the male organs, as shown in ***Figure 10.1A.*** He then dusted the female organ with pollen from the plant he wished to cross it with, as shown in ***Figure 10.1B.*** This process is called cross-pollination. By using this technique, Mendel could be sure of the parents in his cross.

Mendel was a careful researcher

Mendel carefully controlled his experiments and the peas he used. He studied only one trait at a time to control variables, and he analyzed his data mathematically. The tall pea plants he worked with were from populations of plants that had been tall for many generations and had always produced tall offspring. Such plants are said to be true breeding for tallness. Likewise, the short plants he worked with were true breeding for shortness.

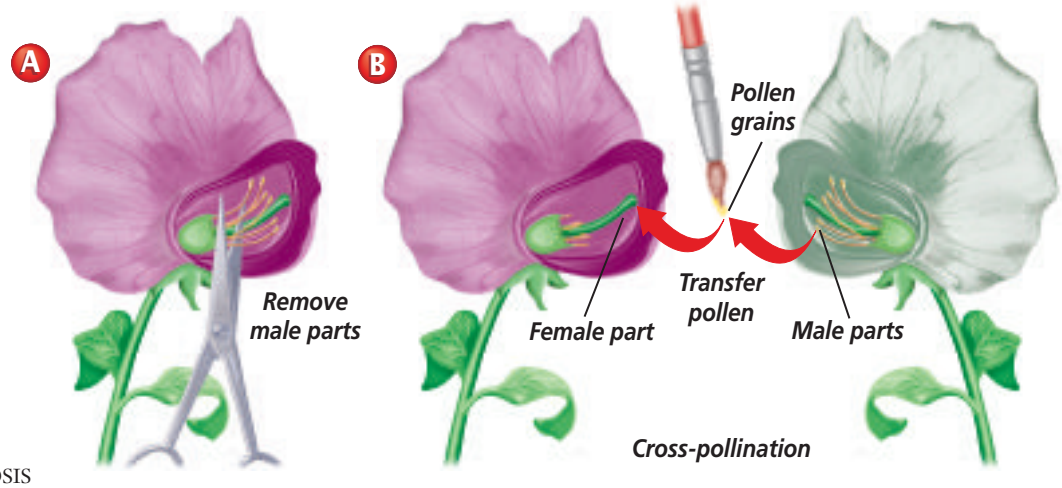


Figure 10.1
In his experiments, Mendel often had to transfer pollen from one plant to another plant with different traits. This is called making a cross.
Describe ***How did Mendel make a cross?***

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Mendel's Monohybrid Crosses

What did Mendel do with the tall and short pea plants he selected? He crossed them to produce new plants. Mendel referred to the offspring of this cross as hybrids. A **hybrid** is the offspring of parents that have different forms of a trait, such as tall and short height. Mendel's first experiments are called monohybrid crosses because *mono* means "one" and the two parent plants differed from each other by a single trait—height.

The first generation

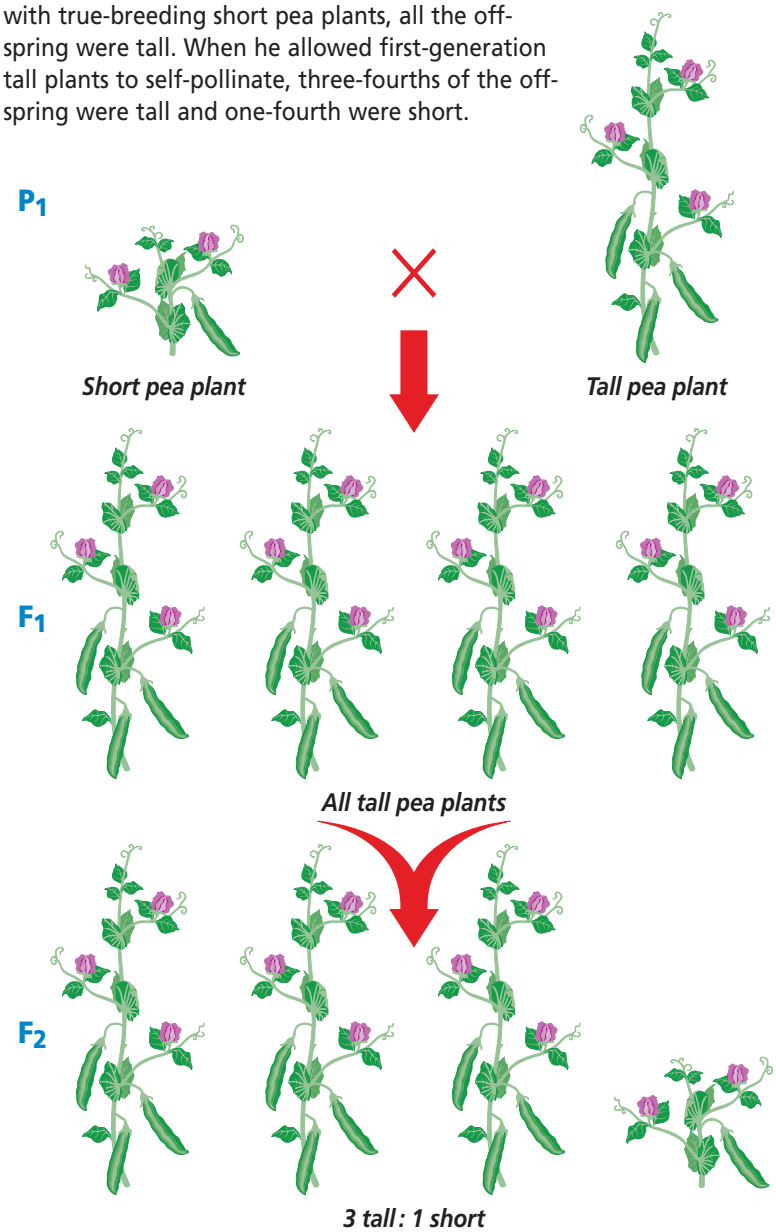
Mendel selected a six-foot-tall pea plant that came from a population of pea plants, all of which were over six feet tall. He cross-pollinated this tall pea plant with pollen from a short pea plant that was less than two feet tall and which came from a population of pea plants that were all short. When he planted the seeds from this cross, he found that all of the offspring grew to be as tall as the taller parent. In this first generation, it was as if the shorter parent had never existed.

The second generation

Next, Mendel allowed the tall plants in this first generation to self-pollinate. After the seeds formed, he planted them and counted more than 1000 plants in this second generation. Mendel found that three-fourths of the plants were as tall as the tall plants in the parent and first generations. He also found that one-fourth of the offspring were as short as the short plants in the parent generation. In other words, in the second generation, tall and short plants occurred in a ratio of about three tall plants to one short plant, as shown in ***Figure 10.2.*** The short trait had reappeared as if from nowhere.

The original parents, the true-breeding plants, are known as the P_1 generation. The *P* stands for "parent." The offspring of the parent plants are known as the F_1 generation. The *F* stands for "filial"—son or daughter. When you cross two F_1 plants with each other, their offspring are the F_2 generation—the second filial generation. You might find it easier to understand these terms if you

Figure 10.2
When Mendel crossed true-breeding tall pea plants with true-breeding short pea plants, all the offspring were tall. When he allowed first-generation tall plants to self-pollinate, three-fourths of the offspring were tall and one-fourth were short.



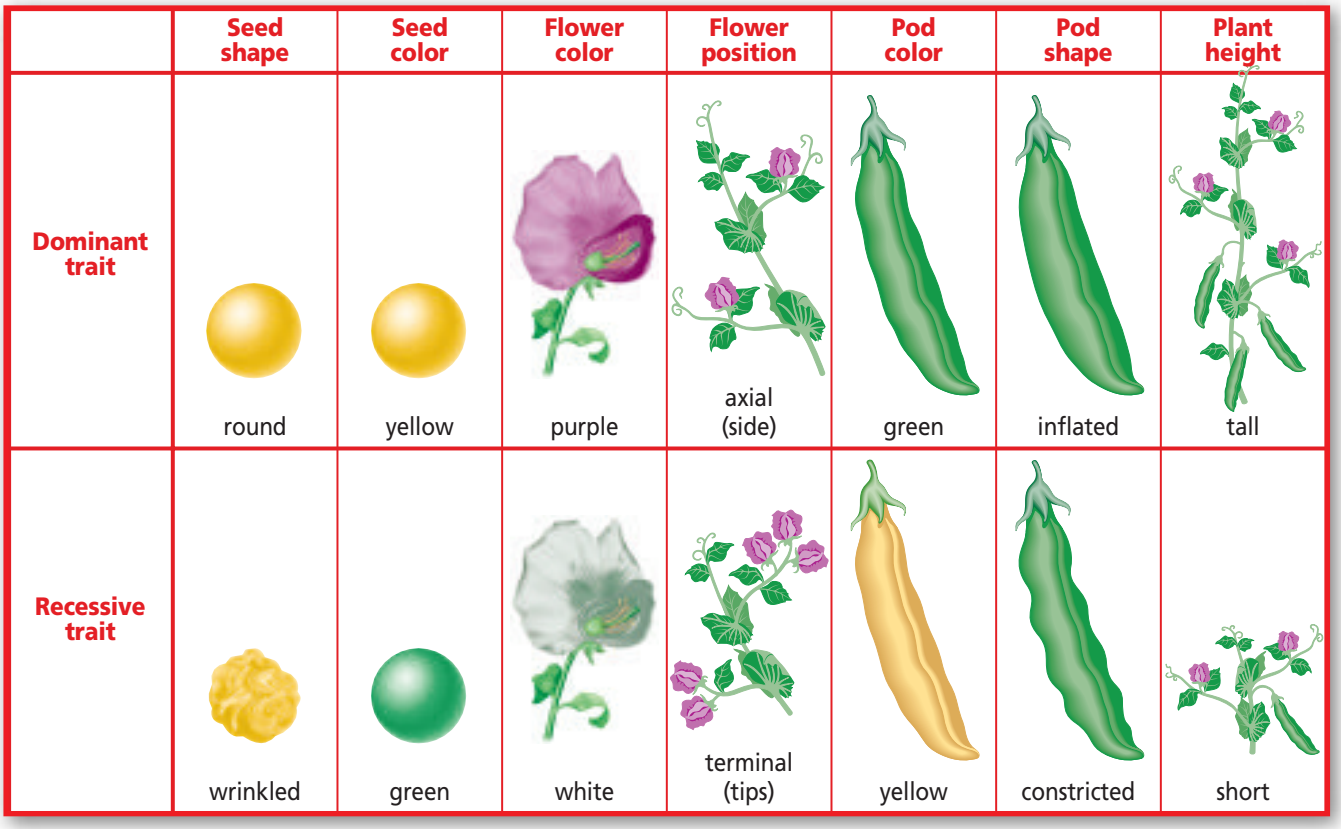


Figure 10.3
Mendel chose seven traits of peas for his experiments. Each trait had two clearly different forms; no intermediate forms were observed. **Compare** ***What genetic variations are observed in plants?***

look at your own family. Your parents are the P_1 generation. You are the F_1 generation, and any children you might have in the future would be the F_2 generation.

Mendel did similar monohybrid crosses with a total of seven pairs of traits, studying one pair of traits at a time. These pairs of traits are shown in ***Figure 10.3.*** In every case, he found that one trait of a pair seemed to disappear in the F_1 generation, only to reappear unchanged in one-fourth of the F_2 plants.

The rule of unit factors

Mendel concluded that each organism has two factors that control each of its traits. We now know that these factors are genes and that they are located on chromosomes. Genes exist in alternative forms. We call these different gene forms **alleles** (uh LEELZ). For example, each of Mendel's pea plants had two alleles of the gene that determined its height. A plant could have two alleles for tallness, two alleles for shortness, or one allele for tallness and one for shortness. An organism's two alleles are located on different copies of a chromosome—one inherited from the female parent and one from the male parent.

Word Origin

allele from the Greek word *allelon,* meaning "of each other"; Genes exist in alternative forms called alleles.

The rule of dominance

Remember what happened when Mendel crossed a tall P_1 plant with a short P_1 plant? The F_1 offspring were all tall. In other words, only one trait was observed. In such crosses, Mendel called the observed trait **dominant** and the trait that disappeared **recessive.** Mendel concluded that the allele for tall plants is dominant to the allele for short plants. Thus, plants that had one allele for tallness and one for shortness were tall.

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Expressed another way, the allele for short plants is recessive to the allele for tall plants. Pea plants with two alleles for tallness were tall, and those with two alleles for shortness were short. You can see in ***Figure 10.4*** how the rule of dominance explained the resulting F_1 generation.

When recording the results of crosses, it is customary to use the same letter for different alleles of the same gene. An uppercase letter is used for the dominant allele and a lowercase letter for the recessive allele. The dominant allele is always written first. Thus, the allele for tallness is written as *T* and the allele for shortness as *t*, as it is in ***Figure 10.4***.

Reading Check **Describe** Mendel's two rules of heredity.

The law of segregation

Now recall the results of Mendel's cross between F_1 tall plants, when the trait of shortness reappeared. To explain this result, Mendel formulated the first of his two laws of heredity. He concluded that each tall plant in the F_1 generation carried one dominant allele for tallness and one unexpressed recessive allele for shortness. Each plant received the allele for tallness from its tall parent and the allele for shortness from its short parent in the P_1 generation. Because each F_1 plant has two different alleles, it can produce two types of gametes—"tall" gametes and "short" gametes. This conclusion, illustrated in ***Figure 10.5*** on the next page, is called the **law of segregation.** The law of segregation states that every individual has two alleles of each gene and when gametes are produced, each gamete receives one of these alleles. During fertilization, these gametes randomly pair to produce four combinations of alleles.

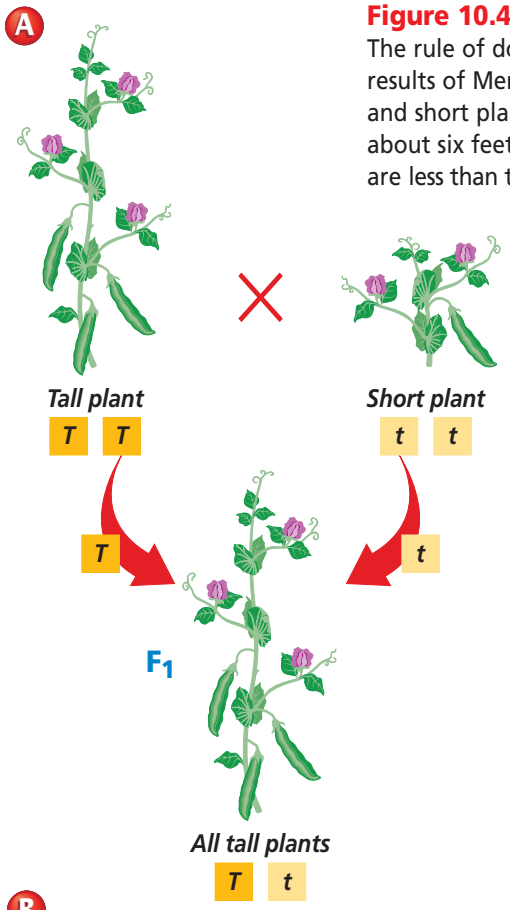

Figure 10.4
The rule of dominance explains the results of Mendel's cross between P_1 tall and short plants **(A).** Tall pea plants are about six feet tall, whereas short plants are less than two feet tall **(B).**

Dwight R. Kuhn

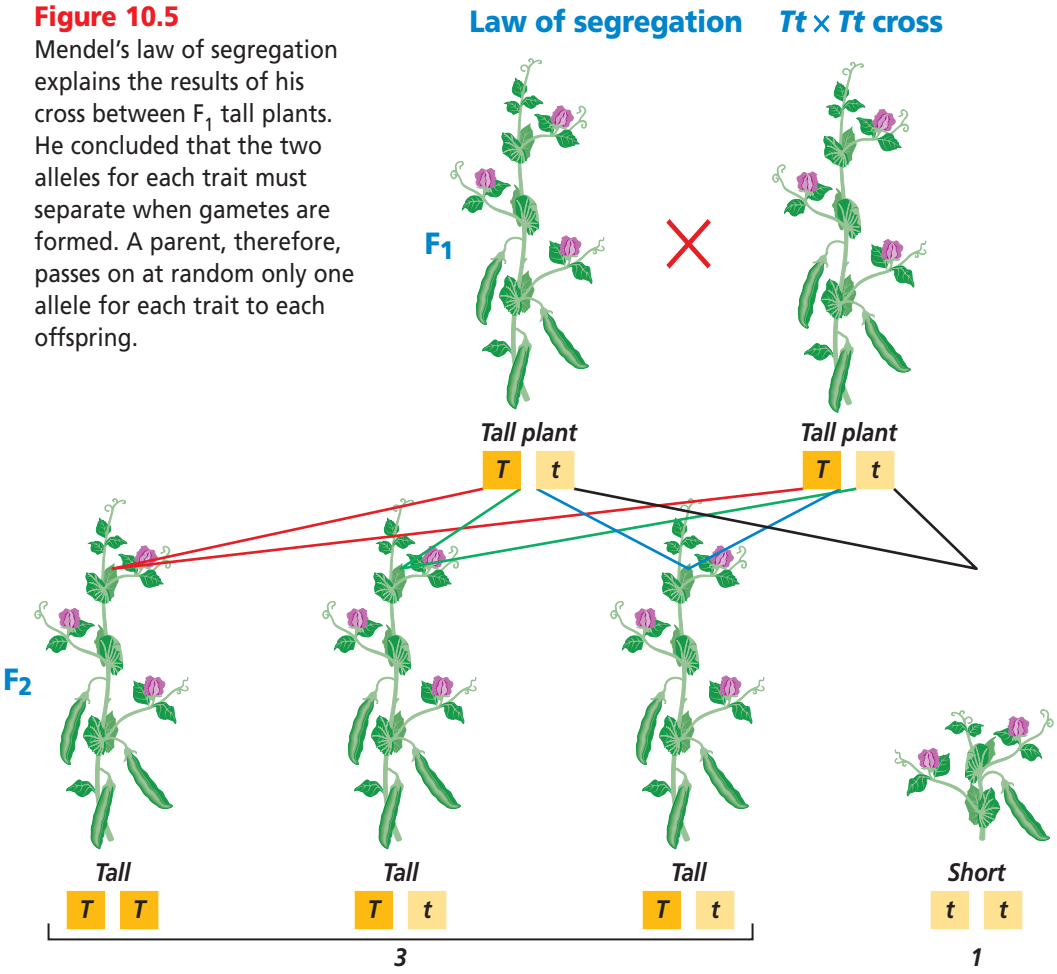

Figure 10.5
Mendel's law of segregation explains the results of his cross between F_1 tall plants. He concluded that the two alleles for each trait must separate when gametes are formed. A parent, therefore, passes on at random only one allele for each trait to each offspring.

Word Origin

phenotype from the Greek words *phainein,* meaning "to show," and *typos,* meaning "model"; The visible characteristics of an organism make up its phenotype.

genotype from the Greek words *gen* or *geno,* meaning "race," and *typos,* meaning "model"; The allele combination of an organism makes up its genotype.

Phenotypes and Genotypes

Mendel showed that tall plants are not all the same. Some tall plants, when crossed with each other, yielded only tall offspring. These were Mendel's original P_1 true-breeding tall plants. Other tall plants, when crossed with each other, yielded both tall and short offspring. These were the F_1 tall plants in ***Figure 10.5*** that came from a cross between a tall plant and a short plant.

Two organisms, therefore, can look alike but have different underlying allele combinations. The way an organism looks and behaves is called its **phenotype** (FEE noh tipe). The phenotype of a tall plant is tall, whether it is *TT* or *Tt*. The allele combination an organism contains is known as its **genotype** (JEE noh tipe). The genotype of a tall plant that has two alleles for tallness is *TT*. The genotype of a tall plant that has one allele for tallness and one allele for shortness is *Tt*. You can see that an organism's genotype can't always be known by its phenotype.

An organism is **homozygous** (hoh moh ZI gus) for a trait if its two alleles for the trait are the same. The true-breeding tall plant that had two alleles for tallness *(TT)* would be homozygous for the trait of height. Because tallness is dominant, a *TT* individual is homozygous dominant for that trait. A short plant would always have two alleles for shortness *(tt)*. It would, therefore, always be homozygous recessive for the trait of height.

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An organism is **heterozygous** (heh tuh roh ZI gus) for a trait if its two alleles for the trait differ from each other. Therefore, the tall plant that had one allele for tallness and one allele for shortness *(Tt)* is heterozygous for the trait of height.

Now look at ***Figure 10.5*** again. Can you identify the phenotype and genotype of each plant? Is each plant homozygous or heterozygous? You can practice determining genotypes and phenotypes in the *BioLab* at the end of this chapter.

Mendel's Dihybrid Crosses

Mendel performed another set of crosses in which he used peas that differed from each other in two traits rather than only one. Such a cross involving two different traits is called a dihybrid cross because *di* means "two." In a dihybrid cross, will the two traits stay together in the next generation or will they be inherited independently of each other?

The first generation

Mendel took true-breeding pea plants that had round yellow seeds *(RRYY)* and crossed them with true-breeding pea plants that had wrinkled green seeds *(rryy)*. He already knew that when he crossed plants that produced round seeds with plants that produced wrinkled seeds, all the plants in the F_1 generation produced seeds that were round. In other words, just as tall plants were dominant to short plants, the round-seeded trait was dominant to the wrinkled-seeded trait. Similarly, when he crossed plants that produced yellow seeds with plants that produced green seeds, all the plants in the F_1 generation produced yellow seeds—yellow was dominant. Therefore, Mendel was not surprised when he found that the F_1 plants of his dihybrid cross all had the two dominant traits of round and yellow seeds, as ***Figure 10.6*** shows.

The second generation

Mendel then let the F_1 plants pollinate themselves. As you might expect, he found some plants that produced round yellow seeds and others that produced wrinkled green seeds. But that's not all. He also found some plants with round green seeds and others with wrinkled yellow seeds. When Mendel sorted and counted the plants of the F_2 generation, he found they appeared in a definite ratio of phenotypes—9 round yellow: 3 round green: 3 wrinkled yellow: 1 wrinkled green. To explain the results of this dihybrid cross, Mendel formulated his second law.

Word Origin

heterozygous
from the Greek words *heteros,* meaning "other," and *zygotos,* meaning "joined together"; A trait is heterozygous when an individual has two different alleles for that trait.

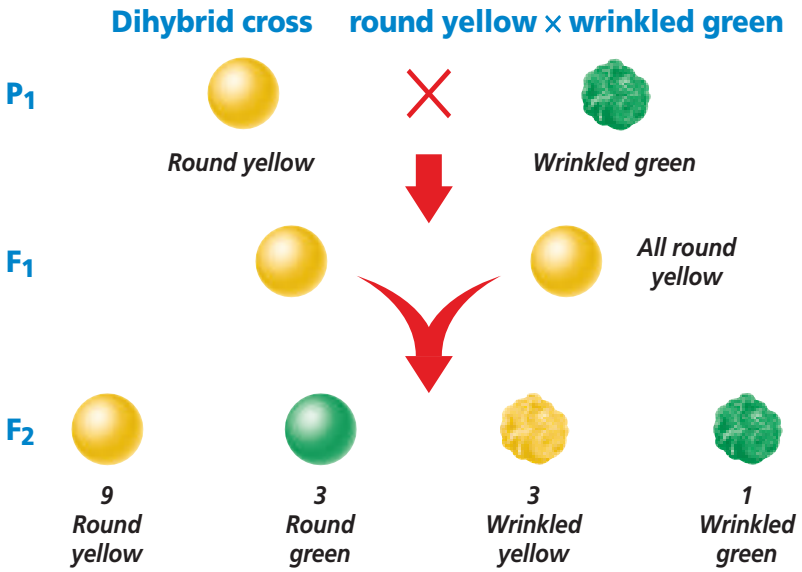

Figure 10.6
When Mendel crossed true-breeding plants that produced round yellow seeds with true-breeding plants that produced wrinkled green seeds, the seeds of all the offspring were round and yellow. When the F_1 plants were allowed to self-pollinate, they produced four different kinds of plants in the F_2 generation.

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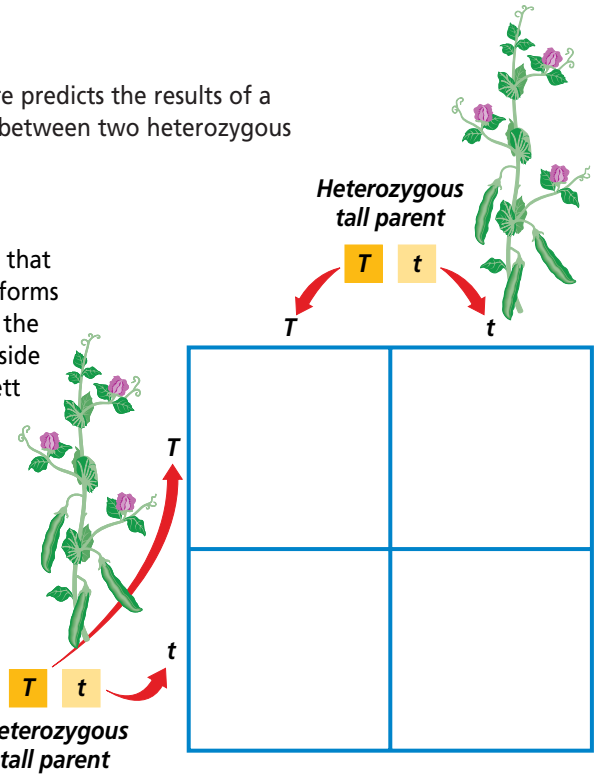
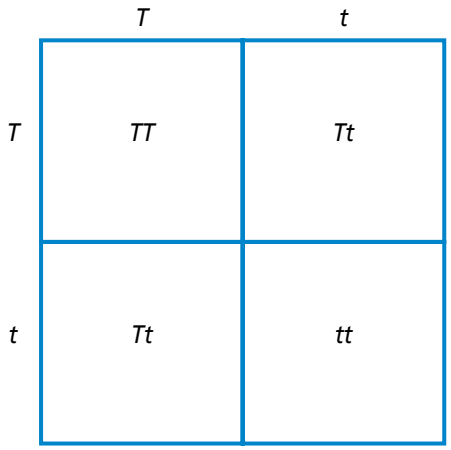
The law of independent assortment

Mendel's second law states that genes for different traits—for example, seed shape and seed color—are inherited independently of each other. This conclusion is known as the **law of independent assortment.** When a pea plant with the genotype *RrYy* produces gametes, the alleles *R* and *r* will separate from each other (the law of segregation) as well as from the alleles *Y* and *y* (the law of independent assortment), and vice versa. These alleles can then recombine in four different ways. If the alleles for seed shape and color were inherited together, only two kinds of pea seeds would have been produced: round yellow and wrinkled green.

Figure 10.7
This Punnett square predicts the results of a monohybrid cross between two heterozygous pea plants.



A The gametes that each parent forms are listed on the top and left side of the Punnett square.



B You can see that there are three different possible genotypes—*TT, Tt,* and *tt*—and that *Tt* can result from two different combinations. **Interpret Scientific Illustrations** ***How many possible phenotypes result from this cross?***

Punnett Squares

In 1905, Reginald Punnett, an English biologist, devised a shorthand way of finding the expected proportions of possible genotypes in the offspring of a cross. This method is called a Punnett square. It takes account of the fact that fertilization occurs at random, as Mendel's law of segregation states. If you know the genotypes of the parents, you can use a Punnett square to predict the possible genotypes of their offspring.

Monohybrid crosses

Consider the cross between two F_1 tall pea plants, each of which has the genotype *Tt*. Half the gametes of each parent would contain the *T* allele, and the other half would contain the *t* allele. A Punnett square for this cross is two boxes tall and two boxes wide because each parent can produce two kinds of gametes for this trait. The two kinds of gametes from one parent are listed on top of the square, and the two kinds of gametes from the other parent are listed on the left side, as ***Figure 10.7A*** shows. It doesn't matter which set of gametes is on top and which is on the side, that is, which parent contributes the *T* allele and which contributes the *t* allele. Refer to the Punnett square in ***Figure 10.7B*** to determine the possible genotypes of the offspring. Each box is filled in with the gametes above and to the left side of that box. You can see that each box then contains two alleles—one possible genotype.

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After the genotypes have been determined, you can determine the phenotypes. Looking again at the Punnett square in ***Figure 10.7B,*** you can see that three-fourths of the offspring are expected to be tall because they have at least one dominant allele. One-fourth are expected to be short because they lack a dominant allele. Of the tall offspring, one-third will be homozygous dominant *(TT)* and two-thirds will be heterozygous *(Tt)*. Note that whereas the genotype ratio is 1*TT*: 2*Tt*: 1*tt*, the phenotype ratio is 3 tall: 1 short. You can practice doing calculations such as Mendel did in the *Connection to Math* at the end of this chapter.

Dihybrid crosses

What happens in a Punnett square when two traits are considered? Think again about Mendel's cross between pea plants producing round yellow seeds and plants producing wrinkled green seeds. All the F_1 plants produced seeds that were round and yellow and were heterozygous for each trait *(RrYy)*. What kind of gametes will these F_1 plants form?

Mendel explained that the traits for seed shape and seed color would be inherited independently of each other. This means that each F_1 plant will produce gametes containing the following combinations of genes with equal frequency: round yellow *(RY)*, round green *(Ry)*, wrinkled yellow *(rY)*, and wrinkled green *(ry)*. A Punnett square for a dihybrid cross will then need to be four boxes on each side for a total of 16 boxes, as ***Figure 10.8*** shows.

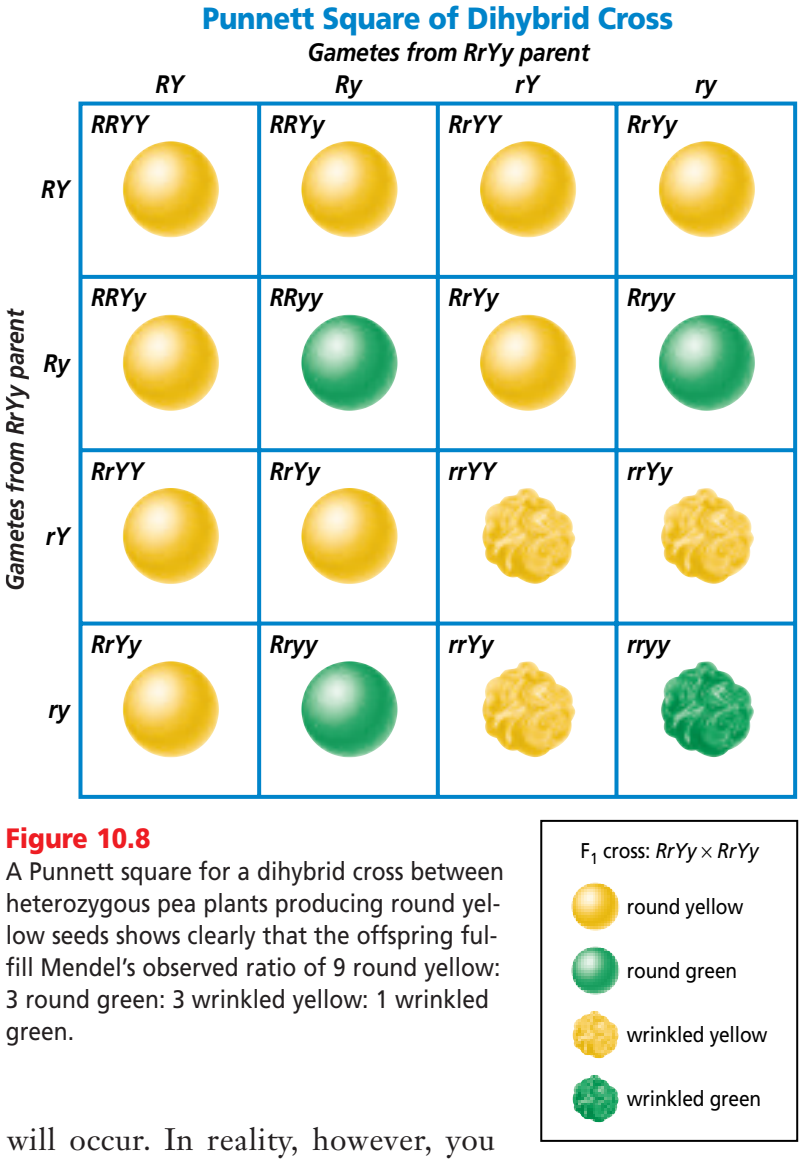


Figure 10.8
A Punnett square for a dihybrid cross between heterozygous pea plants producing round yellow seeds shows clearly that the offspring fulfill Mendel's observed ratio of 9 round yellow: 3 round green: 3 wrinkled yellow: 1 wrinkled green.

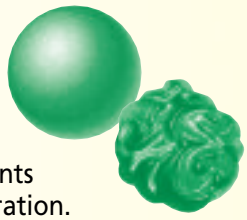
Probability

Punnett squares are good for showing all the possible combinations of gametes and the likelihood that each will occur. In reality, however, you don't get the exact ratio of results shown in the square. That's because, in some ways, genetics is like flipping a coin—it follows the rules of chance.

When you toss a coin, it lands either heads up or tails up. The probability or chance that an event will occur can be determined by dividing the number of desired outcomes by the total number of possible outcomes. Therefore, the probability of getting heads when you toss a coin would be one in two chances, written as 1:2 or ½. A Punnett square can be used to determine the probability of getting a pea plant that produces round seeds when two plants that are heterozygous *(Rr)* are crossed.

Problem-Solving Lab 10.1

Analyze Information



Data Analysis In addition to crossing tall and short pea plants, Mendel crossed plants that formed round seeds with plants that formed wrinkled seeds. He found a 3:1 ratio of round-seeded plants to wrinkled-seeded plants in the F_2 generation.

Solve the Problem

Mendel's F_2 results are shown to the right.

Mendel's Results

Kind of Plant	Number of Plants
Round-seeded	5474
Wrinkled-seeded	1850

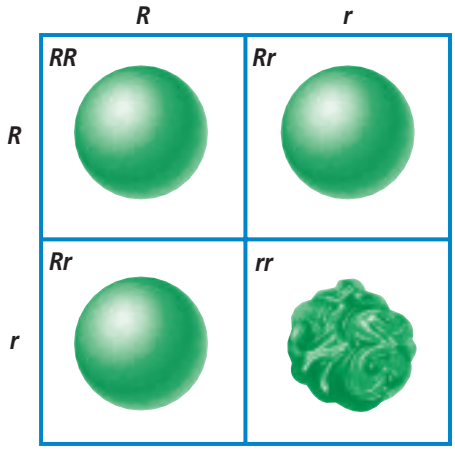
1. Calculate the actual ratio of round-seeded plants to wrinkled-seeded plants by dividing the number of round-seeded plants by the number of wrinkled-seeded plants. Your answer tells you how many more times round-seeded plants resulted than wrinkled-seeded plants.
2. To express your answer as a ratio, write the number from step 1 followed by a colon and the numeral *1*.

Thinking Critically

1. **Compare** How does Mendel's observed ratio compare with the expected 3:1 ratio?
2. **Analyze** Why did the actual and expected ratios differ?

The Punnett square in ***Figure 10.9*** shows three plants with round seeds out of four total plants, so the probability is ¾. Yet, if you calculate the probability of round-seeded plants from Mendel's actual data in the *Problem-Solving Lab* on this page, you will see that slightly less than three-fourths of the plants were round-seeded. It is important to remember that the results predicted by probability are more likely to be seen when there is a large number of offspring.

Figure 10.9
The probability that the offspring from a mating of two heterozygotes will show a dominant phenotype is 3 out of 4, or 3/4.



Section Assessment

Understanding Main Ideas

1. What structural features of pea plant flowers made them suitable for Mendel's genetic studies?
2. What are the genotypes of a homozygous and a heterozygous tall pea plant?
3. One parent is homozygous tall and the other is heterozygous. Make a Punnett square to show how many offspring will be heterozygous.
4. How many different gametes can an *RRYy* parent form? What are they?

Thinking Critically

5. In garden peas, the allele for yellow peas is dominant to the allele for green peas. Suppose you have a plant that produces yellow peas, but you don't know whether it is homozygous dominant or heterozygous. What experiment could you do to find out? Draw Punnett squares to help you.

Skill Review

6. **Observe and Infer** The offspring of a cross between a plant with purple flowers and a plant with white flowers are 23 plants with purple flowers and 26 plants with white flowers. Use the letter *P* for purple and *p* for white. What are the genotypes of the parent plants? Explain your reasoning. For more help, refer to *Observe and Infer* in the **Skill Handbook.**

Section 10.2

SECTION PREVIEW

Objectives

Analyze how meiosis maintains a constant number of chromosomes within a species.

Infer how meiosis leads to variation in a species.

Relate Mendel's laws of heredity to the events of meiosis.

Review Vocabulary

mitosis: the orderly process of nuclear division in which two new daughter cells each receive a complete set of chromosomes (p. 204)

New Vocabulary

diploid
haploid
homologous chromosome
meiosis
sperm
egg
sexual reproduction
crossing over
genetic recombination
nondisjunction

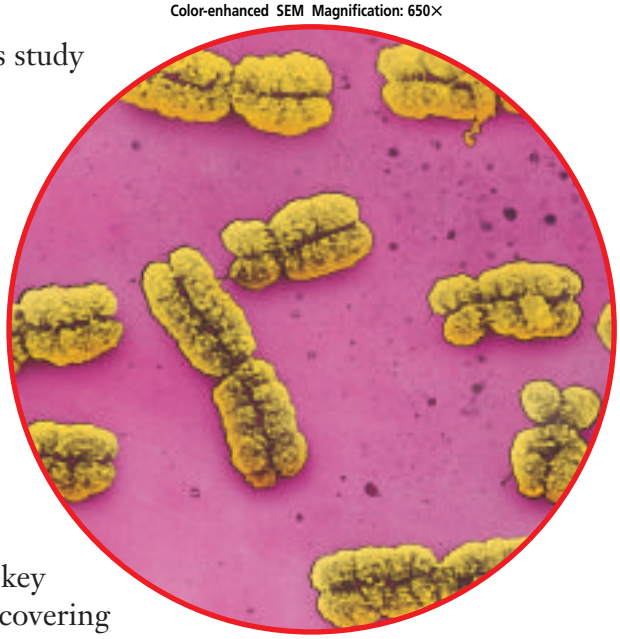
Meiosis

California Standards Standard 2a Students know meiosis is an early step in sexual reproduction in which the pairs of chromosomes separate and segregate randomly during cell division to product gametes containing one chromosome of each type.

Solving the Puzzle

Using an Analogy Mendel's study of inheritance was based on careful observations of pea plants, but pieces of the hereditary puzzle were still missing. Modern technologies such as high-power microscopes allow us a glimpse of things that Mendel could only imagine. Chromosomes, such as those shown here, were the missing pieces of the puzzle because they carry the traits that Mendel described. The key to solving the puzzle was discovering the process by which these traits are transmitted to the next generation.

Color-enhanced SEM Magnification: 650×



Metaphase chromosomes

Organize Information *As you read this section, make a list of the ways in which meiosis explains Mendel's results.*

Genes, Chromosomes, and Numbers

Organisms have tens of thousands of genes that determine individual traits. Genes do not exist free in the nucleus of a cell; they are lined up on chromosomes. Typically, a chromosome can contain a thousand or more genes along its length.

Diploid and haploid cells

If you examined the nucleus in a cell of one of Mendel's pea plants, you would find it had 14 chromosomes—seven pairs. In the body cells of animals and most plants, chromosomes occur in pairs. One chromosome in each pair came from the male parent, and the other came from the female parent. A cell with two of each kind of chromosome is called a **diploid** cell and is said to contain a diploid, or $2n$, number of chromosomes. This pairing supports Mendel's conclusion that organisms have two factors—alleles—for each trait. One allele is located on each of the paired chromosomes.

Organisms produce gametes that contain one of each kind of chromosome. A cell containing one of each kind of chromosome is called a **haploid** cell and is said to contain a haploid, or n, number of chromosomes.

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This fact supports Mendel's conclusion that parent organisms give one factor, or allele, for each trait to each of their offspring.

Each species of organism contains a characteristic number of chromosomes. ***Table 10.1*** shows the diploid and haploid numbers of chromosomes of some species. Note the large range of chromosome numbers. Note also that the chromosome number of a species is not related to the complexity of the organism.

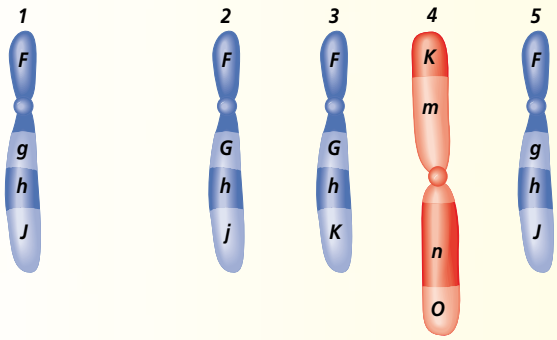
Problem-Solving Lab 10.2

Interpret Scientific Illustrations

Can you identify homologous chromosomes? Homologous chromosomes are paired chromosomes having genes for the same trait located at the same place on the chromosome. The gene itself, however, may have different alleles, producing different forms of the trait.

Solve the Problem

The diagram below shows chromosome 1 with four different genes present. These genes are represented by the letters *F, g, h,* and *J.* Possible homologous chromosomes of chromosome 1 are labeled 2–5. Examine the five chromosomes and the genes they contain to determine which of chromosomes 2–5 are homologous with chromosome 1.



Thinking Critically

1. **Classify** Could chromosome 2 be homologous with chromosome 1? Explain.
2. **Classify** Could chromosome 3 be homologous with chromosome 1? Explain.
3. **Classify** Could chromosome 4 be homologous with chromosome 1? Explain.
4. **Classify** Could chromosome 5 be homologous with chromosome 1? Explain.

Homologous chromosomes

The two chromosomes of each pair in a diploid cell are called **homologous** (hoh MAH luh gus) **chromosomes**. Each of a pair of homologous chromosomes has genes for the same traits, such as plant height. On homologous chromosomes, these genes are arranged in the same order, but because there are different possible alleles for the same gene, the two chromosomes in a homologous pair are not always identical to each other. Identify the homologous chromosomes in the *Problem-Solving Lab.*

Let's look at the seven pairs of homologous chromosomes in the cells of Mendel's peas. These chromosome pairs are numbered 1 through 7. Each pair contains certain genes located at specific places on the chromosome. Chromosome 4 contains the genes for three of the traits that Mendel studied. Many other genes can be found on this chromosome as well.

Every pea plant has two copies of chromosome 4. It received one from each of its parents and will give one at random to each of its offspring. Remember, however, that the two copies of chromosome 4 in a pea plant may not necessarily have identical alleles. Each chromosome can have one of the different alleles possible for each gene. The homologous chromosomes diagrammed in ***Figure 10.10*** show both alleles for each of three traits. Thus, the plant represented by these chromosomes is heterozygous for each of the traits.

Reading Check **Explain** what homologous chromosomes are.

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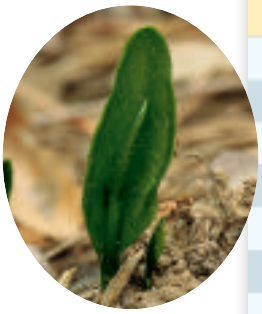
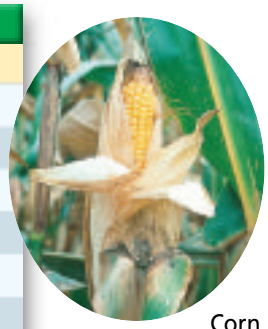


Adder's tongue fern

Table 10.1 Chromosome Numbers of Common Organisms

Organism	Body Cell (2*n*)	Gamete (*n*)
Fruit fly	8	4
Garden pea	14	7
Corn	20	10
Tomato	24	12
Leopard frog	26	13
Apple	34	17
Human	46	23
Chimpanzee	48	24
Dog	78	39
Adder's tongue fern	1260	630



Corn

Leopard frog

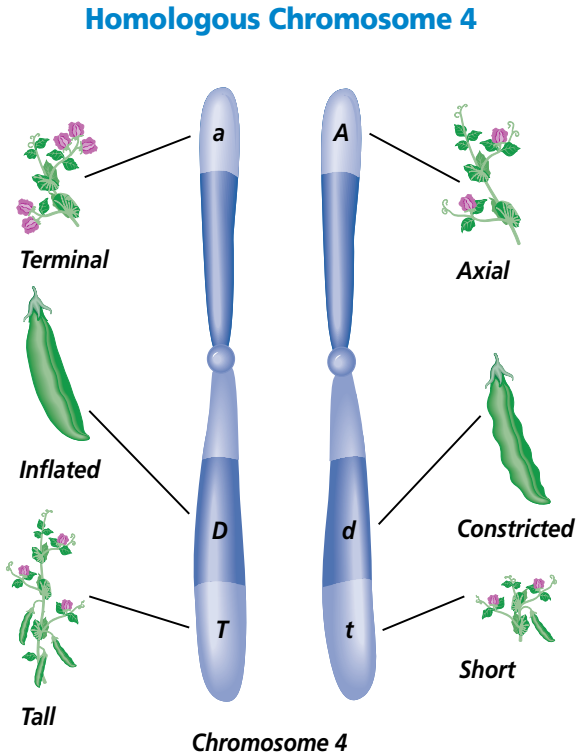
Why meiosis?

When cells divide by mitosis, the new cells have exactly the same number and kind of chromosomes as the original cells. Imagine if mitosis were the only means of cell division. Each pea plant parent, which has 14 chromosomes, would produce gametes that contained a complete set of 14 chromosomes. That means that each offspring formed by fertilization of gametes would have twice the number of chromosomes as each of its parents. The F_1 pea plants would have cell nuclei with 28 chromosomes, and the F_2 plants would have cell nuclei with 56 chromosomes.

Clearly, there must be another form of cell division that allows offspring to have the same number of chromosomes as their parents. This kind of cell division, which produces gametes containing half the number of chromosomes as a parent's body cell, is called **meiosis** (mi OH sus). Meiosis occurs in the specialized body cells of each parent that produce gametes.

Meiosis consists of two separate divisions, known as meiosis I and meiosis II. Meiosis I begins with one diploid (2*n*) cell. By the end of meiosis II, there are four haploid (*n*) cells. These haploid cells are called sex cells—gametes. Male gametes are called **sperm.** Female gametes are called **eggs.** When a sperm fertilizes an egg, the resulting zygote once again has the diploid number of chromosomes.

Figure 10.10
Each chromosome 4 in garden peas contains genes for flower position, pod shape, and height, among others. Flower position can be either axial (flowers located along the stems) or terminal (flowers clustered at the top of the plant). Pod shape can be either inflated or constricted. Plant height can be either tall or short.



The zygote then develops by mitosis into a multicellular organism. This pattern of reproduction, involving the production and subsequent fusion of haploid sex cells, is called **sexual reproduction.** It is illustrated in ***Figure 10.11.***

Reading Check **Explain** why meiosis is necessary in organisms.

The Phases of Meiosis

Word Origin

meiosis from the Greek word *meioun,* meaning "to diminish"; Meiosis is cell division that results in a gamete containing half the number of chromosomes of its parent.

During meiosis, a spindle forms and the cytoplasm divides in the same ways they do during mitosis. However, what happens to the chromosomes in meiosis is very different. ***Figure 10.12*** illustrates interphase and the phases of meiosis. Examine the diagram and photo of each phase as you read about it.

Interphase

Recall from Chapter 8 that, during interphase, the cell replicates its chromosomes. The chromosomes are replicated during interphase that precedes meiosis I, also. After replication, each chromosome consists of two identical sister chromatids, held together by a centromere.

Prophase I

A cell entering prophase I behaves in a similar way to one entering prophase of mitosis. The DNA of the chromosomes coils up and a spindle forms. As the DNA coils, homologous chromosomes line up with each other, gene by gene along their length, to form a four-part structure called a tetrad. A tetrad consists of two homologous chromosomes, each made up of two sister chromatids. The chromatids in a tetrad pair tightly. In fact, they pair so tightly that non-sister chromatids from homologous chromosomes can actually break and exchange genetic material in a process known as **crossing over.** Crossing over can occur at any location on a chromosome, and it can occur at several locations at the same time.

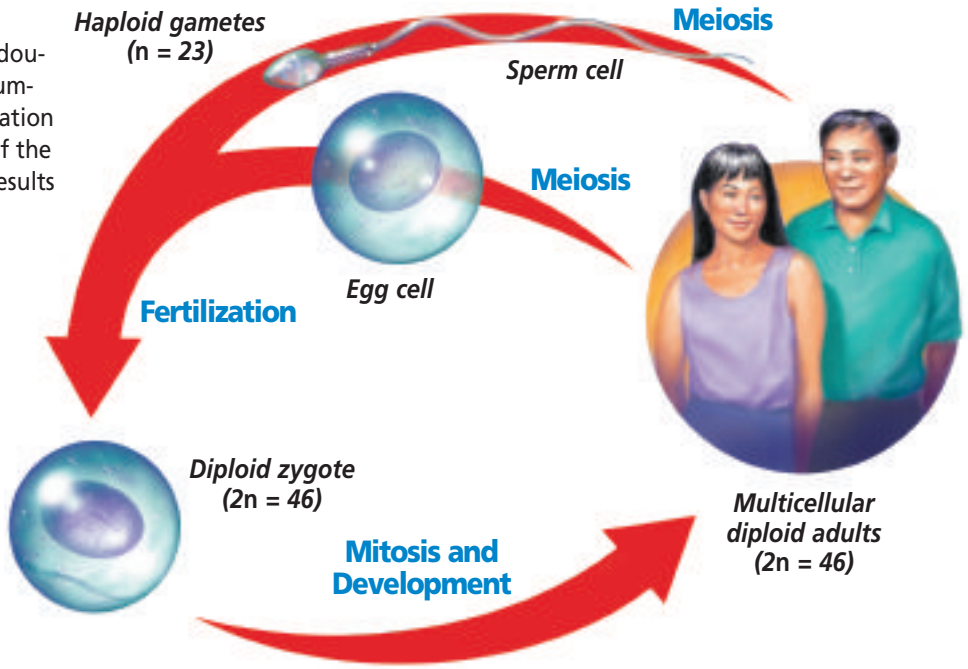
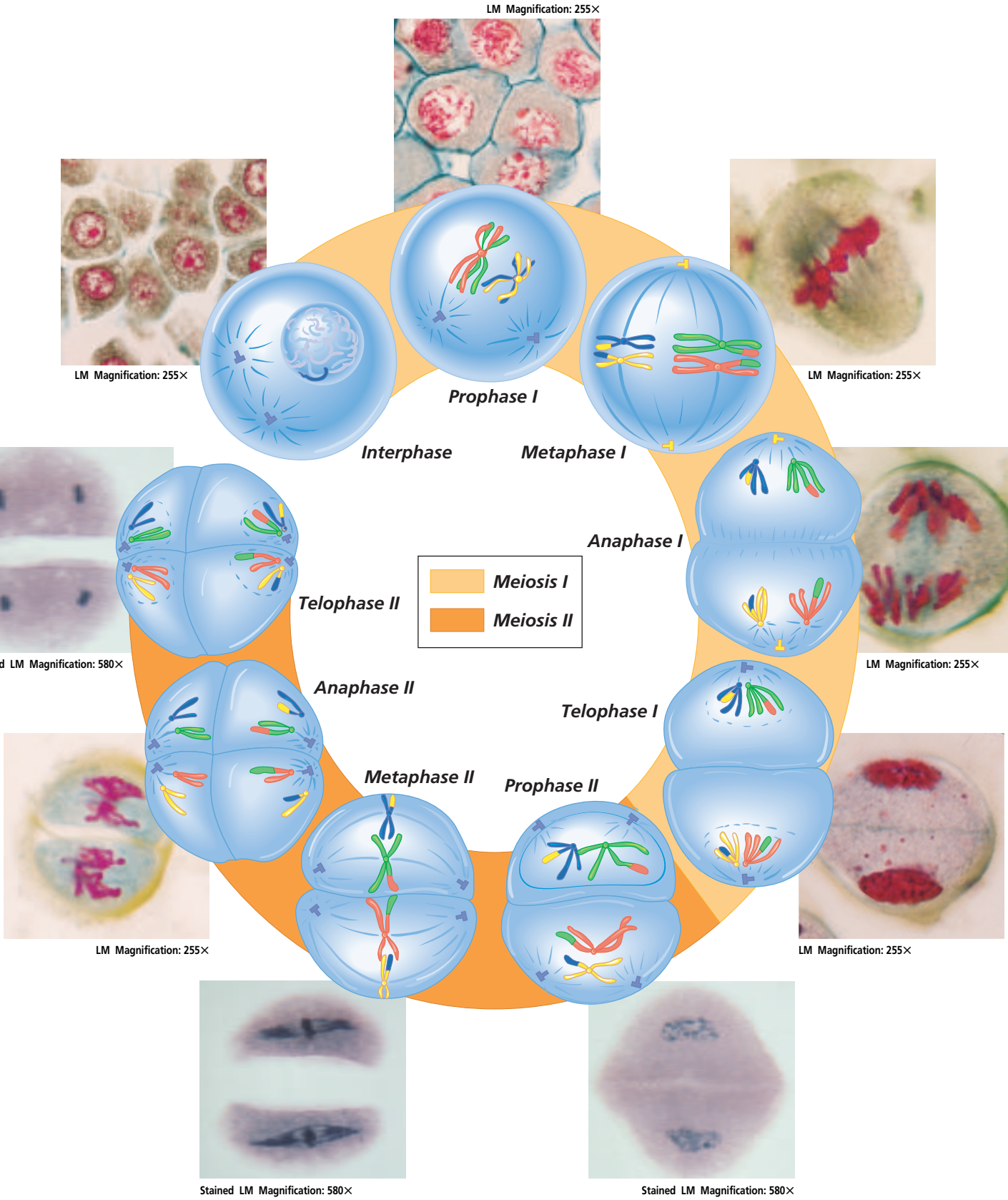


Figure 10.11
In sexual reproduction, the doubling of the chromosome number that results from fertilization is balanced by the halving of the chromosome number that results from meiosis.

Figure 10.12

Compare these diagrams of meiosis with those of mitosis in Chapter 8. After telophase II, meiosis is finished and gametes form. **Compare and Contrast** ***In what other ways are mitosis and meiosis different?***



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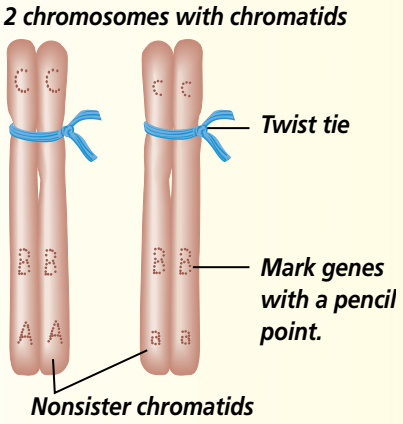
MiniLab 10.2

Formulate Models

Modeling Crossing Over

Crossing over occurs during meiosis and involves only the nonsister chromatids that are present during tetrad formation. The process is responsible for the appearance of new combinations of alleles in gamete cells.



Procedure

1. Copy the data table.
2. Roll out four long strands of clay at least 10 cm long to represent two chromosomes, each with two chromatids.
3. Use the figure above as a guide to joining and labeling these model chromatids. Although there are four chromatids, assume that they started out as a single pair of homologous chromosomes prior to replication. The figure shows tetrad formation during prophase I of meiosis.
4. First, assume that no crossing over takes place. Model the appearance of the chromosomes in the four gamete cells that will result at the end of meiosis. Record your model's appearance by drawing the gametes' chromosomes and their genes in your data table.
5. Next, repeat steps 2–4. This time, however, assume that crossing over occurs between genes B and C.

Data Table

No Crossing Over	Crossing Over
Appearance of chromosomes	Appearance of chromosomes

Analysis

1. **Predict** What will be the appearance of the chromosomes prior to replication?
2. **Compare** Are there any differences in the combinations of alleles on chromosomes in gamete cells when crossing over occurs and when it does not occur?
3. **Analogy** Crossing over has been compared to "shuffling the deck" in cards. Explain what this means.
4. **Think Critically** What would be accomplished if crossing over occurred between sister chromatids? Explain.
5. **Evaluate** Does your model adequately represent crossing over in a cell?

It is estimated that during prophase I of meiosis in humans, there is an average of two to three crossovers for each pair of homologous chromosomes.

This exchange of genetic material is diagrammed in ***Figure 10.13B.*** Crossing over results in new combinations of alleles on a chromosome, as you can see in ***Figure 10.13C.*** You can practice modeling crossing over in the *MiniLab* at the left.

Metaphase I

During metaphase I, the centromere of each chromosome becomes attached to a spindle fiber. The spindle fibers pull the tetrads into the middle, or equator, of the spindle. This is an important step unique to meiosis. Note that homologous chromosomes are lined up side by side as tetrads. In mitosis, on the other hand, they line up on the spindle's equator independently of each other.

Anaphase I

Anaphase I begins as homologous chromosomes, each with its two chromatids, separate and move to opposite ends of the cell. This separation occurs because the centromeres holding the sister chromatids together do not split as they do during anaphase in mitosis. This critical step ensures that each new cell will receive only one chromosome from each homologous pair.

Telophase I

Events occur in the reverse order from the events of prophase I. The spindle is broken down, the chromosomes uncoil, and the cytoplasm divides to yield two new cells. Each cell has half the genetic information of the original cell because it has only one chromosome from each homologous pair. However, another cell division is needed because each chromosome is still doubled.

The phases of meiosis II

The newly formed cells in some organisms undergo a short resting stage. In other organisms, however, the cells go from late anaphase of meiosis I directly to metaphase of meiosis II.

The second division in meiosis is simply a mitotic division of the products of meiosis I. Meiosis II consists of prophase II, metaphase II, anaphase II, and telophase II. During prophase II, a spindle forms in each of the two new cells and the spindle fibers attach to the chromosomes. The chromosomes, still made up of sister chromatids, are pulled to the center of the cell and line up randomly at the equator during metaphase II. Anaphase II begins as the centromere of each chromosome splits, allowing the sister chromatids to separate and move to opposite poles. Finally, nuclei re-form, the spindles break down, and the cytoplasm divides during telophase II. The events of meiosis II are identical to those you studied for mitosis except that the chromosomes do not replicate before they divide at the centromeres.

At the end of meiosis II, four haploid cells have been formed from one diploid cell. Each haploid cell contains one chromosome from each homologous pair. These haploid cells will become gametes, transmitting the genes they contain to offspring.

Meiosis Provides for Genetic Variation

Cells that are formed by mitosis are identical to each other and to the parent cell. Crossing over during meiosis, however, provides a way to rearrange allele combinations. Rather than the alleles from each parent staying together, new combinations of alleles can form. Thus, variability is increased.

Genetic recombination

How many different kinds of sperm can a pea plant produce? Each cell undergoing meiosis has seven pairs of chromosomes. Because each of the seven pairs of chromosomes can line up at the cell's equator in two different ways, 128 different kinds of sperm are possible ($2^n = 2^7 = 128$).

Word Origin

pro- from the Greek word *pro,* meaning "before"

meta- from the Greek word *meta,* meaning "after"

ana- from the Greek word *ana,* meaning "up, back, again"

telo- from the Greek *telos,* meaning "end"

The four phases of cell division are prophase, metaphase, anaphase, and telophase.

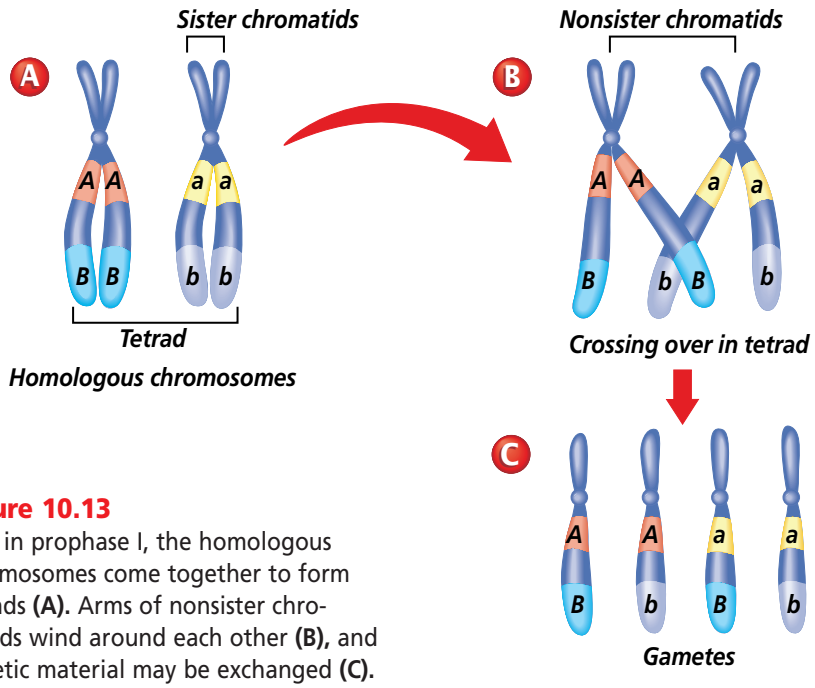


Figure 10.13
Late in prophase I, the homologous chromosomes come together to form tetrads **(A).** Arms of nonsister chromatids wind around each other **(B),** and genetic material may be exchanged **(C).**

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In the same way, any pea plant can form 128 different eggs. Because any egg can be fertilized by any sperm, the number of different possible offspring is 16 384 (128 × 128). A simple example of how genetic recombination occurs is shown in ***Figure 10.14A.*** You can see that the gene combinations in the gametes vary depending on how each pair of homologous chromosomes lines up during metaphase I, a random process.

These numbers increase greatly as the number of chromosomes in the species increases. In humans, $n = 23$, so the number of different kinds of eggs or sperm a person can produce is more than 8 million (2^{23}). When fertilization occurs, $2^{23} \times 2^{23}$, or 70 trillion, different zygotes are possible! It's no wonder that each individual is unique.

In addition, crossing over can occur almost anywhere at random on a chromosome. This means that an almost endless number of different possible chromosomes can be produced by crossing over, providing additional variation to the variation already produced by the random assortment of chromosomes. This reassortment of chromosomes and the genetic information they carry, either by crossing over or by independent segregation of homologous chromosomes, is called **genetic recombination.** It is a major source of variation among organisms. Variation is important to a species because it is the raw material that forms the basis for evolution.

Reading Check **Explain** how crossing over increases genetic variability.

Meiosis explains Mendel's results

The behavior of the chromosomes in meiosis provides the physical basis for explaining Mendel's results. The segregation of chromosomes in anaphase I of meiosis explains Mendel's observation that each parent gives one allele for each trait at random to each offspring, regardless of whether the allele is expressed. The segregation of chromosomes at random during anaphase I also explains how factors, or genes, for different traits are inherited independently of each other. Today, Mendel's laws and the events of meiosis together form the foundation of the chromosome theory of heredity.

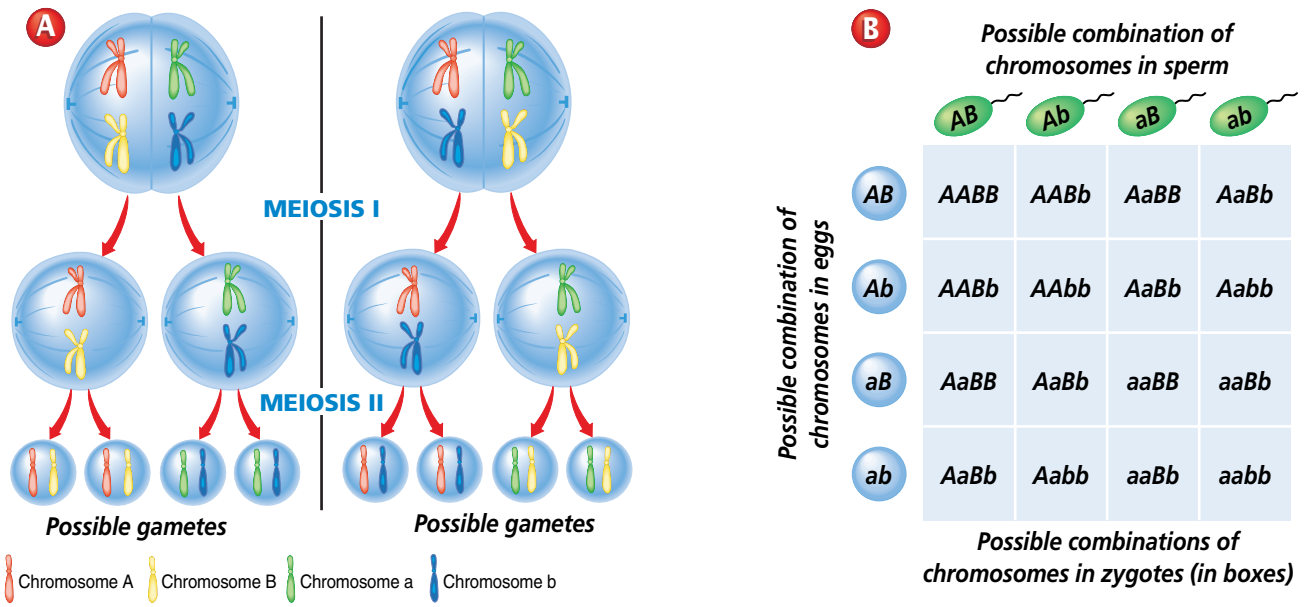

Figure 10.14
If a cell has two pairs of chromosomes—A and a, B and b ($n = 2$)—four kinds of gametes (2^2) are possible, depending on how the homologous chromosomes line up at the equator during meiosis I **(A).** This event is a matter of chance. When zygotes are formed by the union of these gametes, $2^2 \times 2^2$ or 16 possible combinations may occur **(B).**

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Nondisjunction

Although the events of meiosis usually proceed accurately, sometimes chromosomes fail to separate correctly. The failure of homologous chromosomes to separate properly during meiosis is called **nondisjunction.** Recall that during meiosis I, one chromosome from each homologous pair moves to each pole of the cell. In nondisjunction, both chromosomes of a homologous pair move to the same pole of the cell.

In one form of nondisjunction, two kinds of gametes result. One has an extra chromosome, and the other is missing a chromosome. The effects of nondisjunction are often seen after gametes fuse. For example, when a gamete with an extra chromosome is fertilized by a normal gamete, the zygote will have an extra chromosome. This condition is called trisomy (TRI soh mee). In humans, if a gamete with an extra chromosome number 21 is fertilized by a normal gamete, the resulting zygote has 47 chromosomes instead of 46. This zygote will develop into a baby with Down syndrome.

Although organisms with extra chromosomes often survive, organisms lacking one or more chromosomes usually do not. When a gamete with a missing chromosome fuses with a normal gamete during fertilization, the resulting zygote lacks a chromosome. This condition is called monosomy. In humans, most zygotes with monosomy do not survive. If a zygote with monosomy does survive, the resulting organism usually does not. An example of monosomy that is not lethal is Turner syndrome, in which human females have only a single X chromosome instead of two.

Another form of nondisjunction involves a total lack of separation of homologous chromosomes. When this happens, a gamete inherits a complete diploid set of chromosomes, like those shown in ***Figure 10.15.*** When a gamete with an extra set of chromosomes is fertilized by a normal haploid gamete, the offspring has three sets of chromosomes and is triploid. The fusion of two gametes, each with an extra set of chromosomes, produces offspring with four sets of chromosomes—a tetraploid.

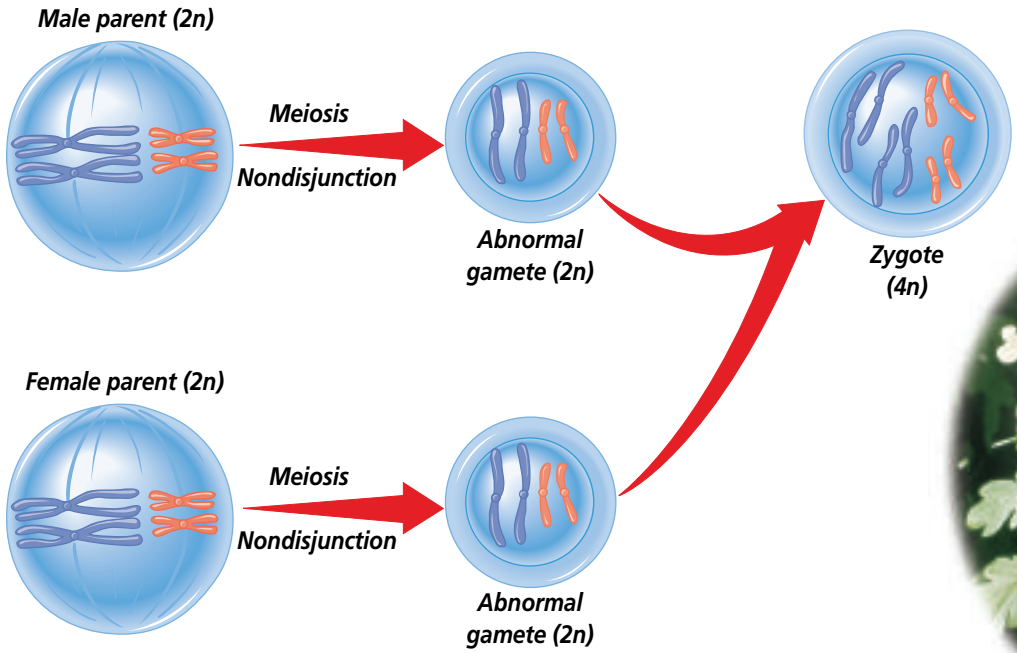


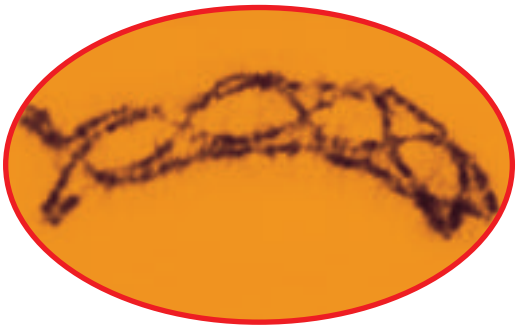
Figure 10.15
Follow the steps to see how a tetraploid plant, such as this chrysanthemum, is produced.

R.B. Satterthwaite

Chromosome Mapping

Figure 10.16

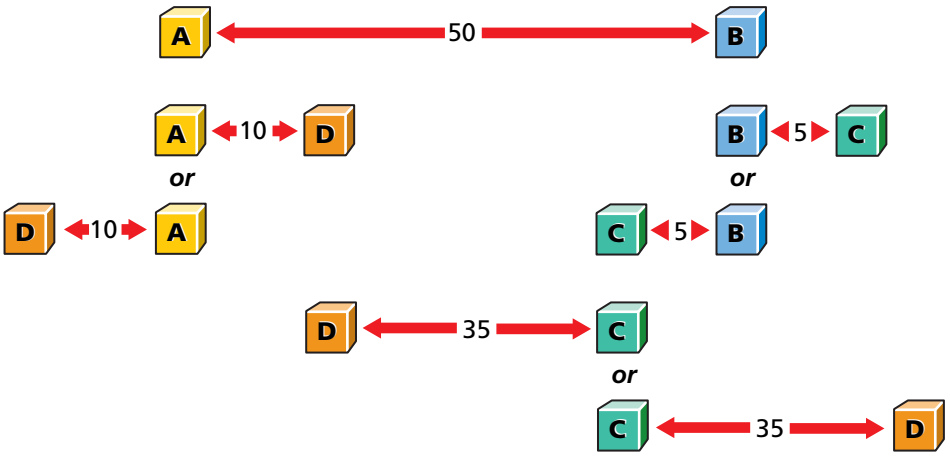
Crossing over, the exchange of genetic material by nonsister chromatids, provides information that can be used to make chromosome maps. Crossing over occurs more frequently between genes that are far apart on a chromosome than between genes that are closer together. **Critical Thinking** ***Why is the frequency of crossing over related to the distance between genes on a chromosome?***



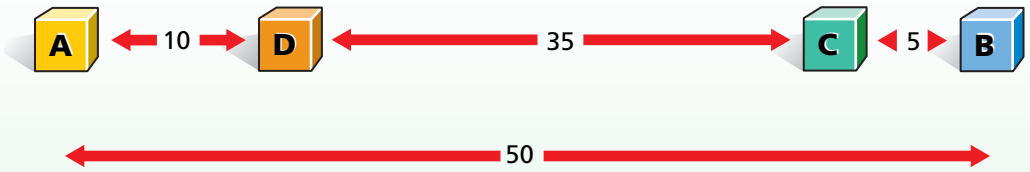
Stained TEM Magnification: 1905×

A Crossing over In prophase I of meiosis, nonsister chromatids cross over, as shown in the photo above. Each X-shaped region is a crossover.

B Mapping Crossing over produces new allele combinations. Geneticists use the frequency of crossing over to map the relative positions of genes on a chromosome. Genes that are farther apart on a chromosome are more likely to have crossing over occur between them than are genes that are closer together.



C Frequencies and distance Suppose there are four genes—A, B, C, and D—on a chromosome. Geneticists determine that the frequencies of recombination among them are as follows: between A and B—50%; between A and D—10%; between B and C—5%; between C and D—35%. The recombination frequencies can be converted to map units: A–B = 50; A–D = 10; B–C = 5; C–D = 35. These map units are not actual distances on the chromosome, but they give relative distances between genes. Geneticists line up the genes as shown above.



D Making the map The genes can be arranged in the sequence that reflects the recombination data. This sequence is a chromosome map.

B. John/Cabisco/Visuals Unlimited

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Polyploidy

Organisms with more than the usual number of chromosome sets are called polyploids. Polyploidy is rare in animals and almost always causes death of the zygote. However, polyploidy frequently occurs in plants. Often, the flowers and fruits of these plants are larger than normal, and the plants are healthier. Many polyploid plants, such as the sterile banana plant shown in ***Figure 10.17***, are of great commercial value.

Meiosis is a complex process, and the results of an error occurring are sometimes unfortunate. However, the resulting changes can be beneficial, such as those that have occurred in agriculture. Hexaploid ($6n$) wheat, triploid ($3n$) apples, and polyploid chrysanthemums all are available commercially. You can see that a thorough understanding of meiosis and genetics would be very helpful to plant breeders. In fact, plant breeders have learned to produce polyploid plants artificially by using chemicals that cause nondisjunction.

Figure 10.17
The banana plant is an example of a triploid plant. **Think Critically** ***Why do you think the banana plant is sterile?***

Gene Linkage and Maps

Genes sometimes appear to be inherited together instead of independently. If genes are close together on the same chromosome, they usually are inherited together. These genes are said to be linked. In fact, all the genes on a chromosome usually are linked and inherited together. It is the chromosomes, rather than the individual genes, that follow Mendel's law of independent assortment.

Linked genes may become separated on different homologous chromosomes as a result of crossing over. When crossing over produces new gene combinations, geneticists can use the frequencies of these new gene combinations to make a chromosome map showing the relative locations of the genes. ***Figure 10.16*** illustrates this process.

Section Assessment

Understanding Main Ideas

1. How are the cells at the end of meiosis different from the cells at the beginning of meiosis? Use the terms *chromosome number, haploid,* and *diploid* in your answer.
2. What is the significance of meiosis to sexual reproduction?
3. Why are there so many varied phenotypes within a species such as humans?
4. If the diploid number of a plant is 10, how many chromosomes would you expect to find in its triploid offspring?

Thinking Critically

5. How do the events that take place during meiosis explain Mendel's law of independent assortment?

Skill Review

6. **Get the Big Picture** Compare ***Figures 10.12*** and ***8.13*** of meiosis and mitosis. Explain why crossing over between nonsister chromatids of homologous chromosomes cannot occur during mitosis. For more help, refer to *Get the Big Picture* in the **Skill Handbook.**

INTERNET

BioLab

How can phenotypes and genotypes of plants be determined?

Before You Begin

It's difficult to predict the traits of plants if all that you see is their seeds. But if these seeds are planted and allowed to grow, certain traits will appear. By observing these traits, you might be able to determine the possible phenotypes and genotypes of the parent plants that produced these seeds. In this lab, you will determine the genotypes of plants that grow from two groups of tobacco seeds. Each group of seeds came from different parents. Plants will be either green or albino (white) in color. Use the following genotypes for this cross. *CC* = green, *Cc* = green, and *cc* = albino

Matt Meadows

PREPARATION

Problem

Can the phenotypes and genotypes of the parent plants that produced two groups of seeds be determined from the phenotypes of the plants grown from the seeds?

Hypotheses

Have your group agree on a hypothesis to be tested that will answer the problem question. Record your hypothesis.

Objectives

In this BioLab, you will:

- **Analyze** the results of growing two groups of seeds.
- **Draw conclusions** about phenotypes and genotypes based on those results.
- **Use the Internet** to collect and compare data from other students.

Possible Materials

potting soil
small flowerpots or seedling flats
two groups of tobacco seeds
hand lens
light source
thermometer or temperature probe
plant-watering bottle

Safety Precautions

CAUTION: ***Always wash your hands after handling plant materials. Always wear goggles in the lab.***

Skill Handbook

If you need help with this lab, refer to the **Skill Handbook.**

PLAN THE EXPERIMENT

1. Examine the materials provided by your teacher. As a group, make a list of the possible ways you might test your hypothesis.
2. Agree on one way that your group could investigate your hypothesis.

3. Design an experiment that will allow you to collect quantitative data. For example, how many plants do you think you will need to examine?
4. Prepare a numbered list of directions. Include a list of materials and the quantities you will need.
5. Make a data table for recording your observations.

Check the Plan

1. Carefully determine what data you are going to collect. How many seeds will you need? How long will you carry out the experiment?
2. What variables, if any, will have to be controlled? (Hint: Think about the growing conditions for the plants.)
3. ***Make sure your teacher has approved your experimental plan before you proceed further.***
4. Carry out your experiment. Make any needed observations, such as the numbers of green and albino plants in each group, and complete your data table.
5. Visit ca.bdol.glencoe.com/internet_lab to post your data.
6. **CLEANUP AND DISPOSAL** Make wise choices in the disposal of materials.

ANALYZE AND CONCLUDE

1. **Think Critically** Why was it necessary to grow plants from the seeds in order to determine the phenotypes of the plants that formed the seeds?
2. **Draw Conclusions** Using the information in the introduction, describe how the gene for green color *(C)* is inherited.
3. **Make Inferences** For the group of seeds that yielded all green plants, are you able to determine exactly the genotypes of the parents that formed these seeds? Can you determine the genotype of each plant observed? Explain.
4. **Make Inferences** For the group of seeds that yielded some green and some albino plants, are you able to determine exactly the genotypes of the plants that formed these seeds? Can you determine the genotype of each plant observed? Explain.
5. **ERROR ANALYSIS** Use the data posted on ca.bdol.glencoe.com/internet_lab to compare your experimental design with that of other students. Were your results similar? What might account for the differences?

Share Your Data

Find this BioLab using the link below and post your results in the table provided. Briefly describe your experimental design.

ca.bdol.glencoe.com/internet_lab

connection to Math

A Solution from Ratios

In 1866, Gregor Mendel, an Austrian monk, published the results of eight years of experiments with garden peas. His work was ignored until 1900, when it was rediscovered.

Mendel had three qualities that led to his discovery of the laws of heredity. First, he was curious, impelled to find out why things happened. Second, he was a keen observer. Third, he was a skilled mathematician. Mendel was the first biologist who relied heavily on statistics for solutions to how traits are inherited.

Darwin missed his chance About the same time that Mendel was carrying out his experiments with pea plants, Charles Darwin was gathering data on snapdragon flowers. When Darwin crossed plants that had normal-shaped flowers with plants that had odd-shaped flowers, all the offspring had normal-shaped flowers. He thought the two traits had blended. When he allowed the F_1 plants to self-pollinate, his results were 88 plants with normal-shaped flowers and 37 plants with odd-shaped flowers. Darwin was puzzled by the results and did not continue his studies with these plants. Lacking Mendel's statistical skills, Darwin failed to see the significance of the ratio of normal-shaped flowers to odd-shaped flowers in the F_2 generation. What was this ratio? Was it similar to Mendel's ratio of dominant to recessive traits in pea plants?

Finding the ratios for four other traits ***Figure 10.3*** on page 256 shows seven traits that Mendel studied in pea plants. You have already looked at Mendel's data for plant height and seed shape. Now use the data for seed color, flower position, pod color, and pod shape to find the ratios of dominant to recessive for these traits in the F_2 generation.

Draw Table B in your notebook or journal. Calculate the ratios for the data in Table A and complete Table B by following these steps:

- Step 1 Divide the larger number by the smaller number.
- Step 2 Round to the nearest hundredth.
- Step 3 To express your answer as a ratio, write the number from step 2 followed by a colon and the number *1*.

Table A Mendel's Results

Seed Color	Flower Position	Pod Color	Pod Shape
Yellow 6022	Axial 651	Green 428	Inflated 882
Green 2001	Terminal 207	Yellow 152	Constricted 299

Table B Calculating Ratios for Mendel's Results

	Seed Color	Flower Position	Pod Color	Pod Shape
Calculation	$\frac{6022}{2001} = 3.00$			
Ratio	3:1 yellow: green			

Math in Biology

Think Critically Why are ratios so important in understanding how dominant and recessive traits are inherited?

To find out more about Mendel's work, visit ca.bdol.glencoe.com/math

CONTENTS

Chapter 10 Assessment

Study Guide

Section 10.1

Mendel's Laws of Heredity

Key Concepts

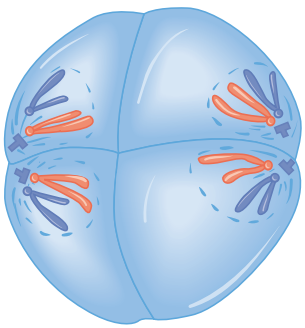
- Genes are located on chromosomes and exist in alternative forms called alleles. A dominant allele can mask the expression of a recessive allele.
- When Mendel crossed pea plants differing in one trait, one form of the trait disappeared until the second generation of offspring. To explain his results, Mendel formulated the law of segregation.
- Mendel formulated the law of independent assortment to explain that two traits are inherited independently.
- Events in genetics are governed by the laws of probability.

Vocabulary

allele (p. 256)
dominant (p. 256)
fertilization (p. 253)
gamete (p. 253)
genetics (p. 253)
genotype (p. 258)
heredity (p. 253)
heterozygous (p. 259)
homozygous (p. 258)
hybrid (p. 255)
law of independent assortment (p. 260)
law of segregation (p. 257)
phenotype (p. 258)
pollination (p. 254)
recessive (p. 256)
trait (p. 253)
zygote (p. 253)

Section 10.2

Meiosis



Key Concepts

- In meiosis, one diploid ($2n$) cell produces four haploid (n) cells, providing a way for offspring to have the same number of chromosomes as their parents.
- In prophase I of meiosis, homologous chromosomes come together and pair tightly. Exchange of genetic material, called crossing over, takes place.
- Mendel's results can be explained by the distribution of chromosomes during meiosis.
- Random assortment and crossing over during meiosis provide for genetic variation among the members of a species.
- The outcome of meiosis may vary due to nondisjunction, the failure of chromosomes to separate properly during cell division.
- All the genes on a chromosome are linked and are inherited together. It is the chromosomes rather than the individual genes that are assorted independently.

Vocabulary

crossing over (p. 266)
diploid (p. 263)
egg (p. 265)
genetic recombination (p. 270)
haploid (p. 263)
homologous chromosome (p. 264)
meiosis (p. 265)
nondisjunction (p. 271)
sexual reproduction (p. 266)
sperm (p. 265)

FOLDABLES Study Organizer

To help you review Mendel's work, use the Organizational Study Fold on page 253.

Chapter 10 Assessment

Vocabulary Review

Review the Chapter 10 vocabulary words listed in the Study Guide on page 277. For each set of vocabulary words, choose the one that does not belong. Explain why it does not belong.

1. egg—sperm—zygote
2. homozygous—hybrid—heterozygous
3. phenotype—genotype—allele
4. nondisjunction—genetic recombination—crossing over
5. zygote—diploid—gamete

Understanding Key Concepts

6. At the end of meiosis, how many haploid cells have been formed from the original cell?
   A. one **C.** three
   B. two **D.** four
7. When Mendel transferred pollen from one pea plant to another, he was _____ the plants.
   A. self-pollinating **C.** self-fertilizing
   B. cross-pollinating **D.** cross-fertilizing
8. Which of these does NOT show a recessive trait in garden peas?
   A.  **B.**  **C.**  **D.** 
9. During what phase of meiosis do sister chromatids separate?
   A. prophase I **C.** anaphase II
   B. telophase I **D.** telophase II
10. During what phase of meiosis do nonsister chromatids cross over?
    A. prophase I **C.** telophase I
    B. anaphase I **D.** telophase II
11. A dihybrid cross between two heterozygotes produces a phenotypic ratio of _____.
    A. 3:1 **C.** 9:3:3:1
    B. 1:2:1 **D.** 1:6:9

Constructed Response

12. **Open Ended** On the average, each human has about six recessive alleles that would be lethal if expressed. Why do you think that human cultures have laws against marriage between close relatives?
13. **Open Ended** How does separation of homologous chromosomes during anaphase I of meiosis increase variation among offspring?
14. **Open Ended** Relating to the methods of science, why do you think it was important for Mendel to study only one trait at a time during his experiments?
15. **Open Ended** Explain why sexual reproduction is an advantage to a population that lives in a rapidly changing environment.

Thinking Critically

16. **Observe and Infer** Why is it possible to have a family of six girls and no boys, but extremely unlikely that there will be a public school with 500 girls and no boys?
17. **Recognize Cause and Effect** Why is it sometimes impossible to determine the genotype of an organism that has a dominant phenotype?
18. **Observe and Infer** While examining a cell in prophase I of meiosis, you observe a pair of homologous chromosomes pairing tightly. What is the significance of the places at which the chromosomes are joined?
19. **REAL WORLD BIOCHALLENGE** Several human genetic disorders result from nondisjunction in meiosis, including Down syndrome, Kleinfelter's syndrome, and Turner syndrome. Visit ca.bdol.glencoe.com to investigate these disorders. What characteristic is common to each? Choose one of these disorders, or another human disorder caused by nondisjunction, and prepare a visual display that explains the disorder. Explain the disorder to your class.

Chapter 10 Assessment

California Standards Practice

The assessed California standard appears next to the question.

All questions aligned and verified by The Princeton Review

Part 1 Multiple Choice

Use the diagram to answer questions 20–23.

	T	*t*
T	1	2
t	3	4

20. Which of the following is true?
3a **A.** Individual 1 is heterozygous.
B. Individuals 2 and 3 are homozygous.
C. Individual 4 is recessive.
D. All individuals will be male.

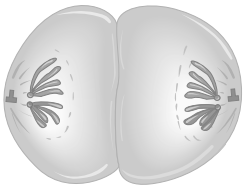
21. Which of the following has the *Tt* genotype?
3a **A.** 1 **C.** 3
B. 2 **D.** 2 and 3

22. If *T* is the allele for purple flowers and *t* is
3a the allele for white flowers, the results would be _____.
A. 3 out of 4 are purple
B. 3 out of 4 are white
C. equal numbers of white and purple
D. all of the same color

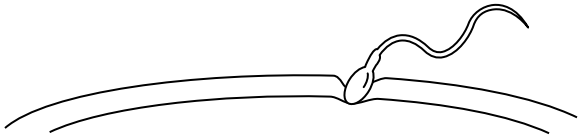
23. Which of Mendel's observations would
3b describe the results of the experimental cross in question 22?
A. rule of dominance
B. law of segregation
C. law of independent assortment
D. rule of unit factors

24. Recessive traits appear only when an
3a organism is _____.
A. mature
B. different from its parents
C. heterozygous
D. homozygous

25. The stage of meiosis shown
2a here is _____.
A. anaphase I
B. metaphase II
C. telophase I
D. telophase II



Study the diagram and answer questions 26–28.



26. What name is given to the process shown above?
A. fertilization **C.** meiosis
B. zygote **D.** gametes

27. What name is given to the cells shown in the diagram above?
A. fertilization **C.** meiosis
B. zygotes **D.** gametes

28. If each of the cells shown in the diagram has
2e 16 chromosomes, how many chromosomes would you expect to find in a skin cell of the resulting organism?
A. 16 **C.** 32
B. 64 **D.** 8

Part 2 Constructed Response/Grid In

Record your answers on your answer document.

29. **Open Ended** Explain the difference between trisomy and triploidy. Describe a way that each condition could occur. Use diagrams to clarify your answer.

30. **Open Ended** Compare metaphase of mitosis with metaphase I of meiosis. Explain the significance of the differences between the two stages in terms of sexual reproduction and genetic variation.