Chapter 12

Mendel and Heredity

The common corn snake (*Elaphe guttata*) is a popular pet. Snake breeders have discovered many variations of colors and patterns in this species.

Preview

Why It Matters

Your genetic makeup influences your appearance, your personality, your abilities, and your health. We now know that many human traits, such as talents and diseases, have their origins in genes. As we come to understand how traits are inherited, we can use this information to better our lives.

Section 1

Origins of Hereditary Science

Key Ideas	Key Terms	Why It Matters
› Why was Gregor Mendel important for modern genetics? › Why did Mendel conduct experiments with garden peas? › What were the important steps in Mendel's first experiments? › What were the important results of Mendel's first experiments?	character trait hybrid generation	Our understanding of genetics, including what makes us unique, can be traced back to Mendel's discoveries.

Since they first learned how to breed plants and animals, people have been interested in heredity. In the 1800s, one person figured out some of the first key ideas of genetics. Recall that *genetics* is the science of heredity and the mechanism by which traits are passed from parents to offspring.

Mendel's Breeding Experiments

A monk named Gregor Johann Mendel lived in the 1800s in Austria. Mendel did breeding experiments with the garden pea plant, *Pisum sativum,* shown in **Figure 1.** Farmers had done similar experiments before, but Mendel was the first person to develop rules that accurately predict the patterns of heredity in pea plants. › **Modern genetics is based on Mendel's explanations for the patterns of heredity in garden pea plants.**

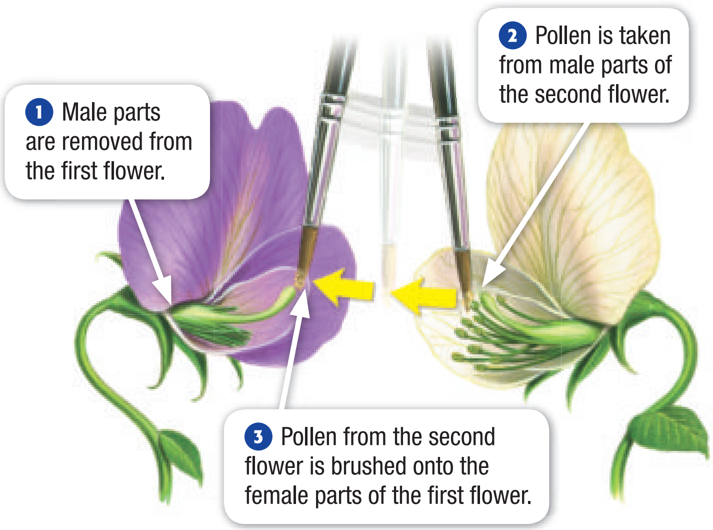
As a young man, Mendel studied to be a priest. Later, he went to the University of Vienna. There, he learned how to study science through experimentation and how to use mathematics to explain natural events. Mendel lived the rest of his life in a monastery, where he taught high school and cared for a garden. It was in this garden that he completed his important experiments.

Most of Mendel's experiments involved crossing different types of pea plants. In this case, the word *cross* means "to mate or breed two individuals." Mendel crossed a type of garden pea plant that had purple flowers with a type that had white flowers. All of the offspring from that cross had purple flowers. However, when two of these purple-flowered offspring were crossed, some offspring had white flowers and some had purple flowers.

The white color had reappeared in the second group of offspring! Mendel decided to investigate this strange occurrence. So, he carefully crossed different types of pea plants and recorded the numbers of each type of offspring. He did this experiment many times.

› **Reading Check** ***How did Mendel experiment with pea plants? (See the Appendix for answers to Reading Checks.)***

Figure 1 To cross plants that each had flowers of a different color, Mendel controlled the pollen that fertilized each flower.



Features of Pea Plants

Mendel studied seven features in his pea plants, as **Figure 2** shows. **The garden pea plant is a good subject for studying heredity because the plant has contrasting traits, usually self-pollinates, and grows easily.**

Contrasting Traits In the study of heredity, physical features that are inherited are called **characters.** Several characters of the garden pea plant exist in two clearly different forms. The plant's flower color is either purple or white—there are no intermediate forms. A **trait** is one of several possible forms of a character. Purple is one of two possible traits for the flower-color character in pea plants. Other contrasting traits of pea plants are shown in **Figure 2.** (For some characters, more than two traits may be possible). Mendel wanted to see what would happen when he crossed individuals that have different traits. In such a cross, the offspring that result are called **hybrids.**

ACADEMIC VOCABULARY

contrast to show differences when compared.

character a recognizable inherited feature or characteristic of an organism

trait a genetically determined characteristic

hybrid the offspring of a cross between parents that have contrasting traits

generation the entire group of offspring produced by a given group of parents

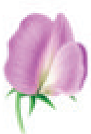
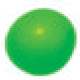
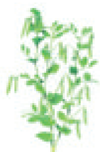
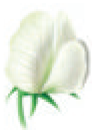
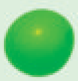
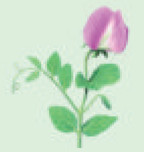
Self-Pollination In garden pea plants, each flower contains both male and female reproductive parts. This arrangement allows the plant to *self-pollinate,* or fertilize itself. Pea plants can also reproduce through *cross-pollination*. This process occurs when pollen from the flower of one plant is carried by insects or by other means to the flower of another plant. To cross-pollinate two pea plants, Mendel had to make sure that the plants could not self-pollinate. So, he removed the male parts (which produce pollen) from some of the flowers. But he did not remove the female parts (which produce eggs, fruit, and seeds). Then, he dusted the female parts of one plant with pollen from another plant.

Easy to Grow The garden pea is a small plant that needs little care and matures quickly. Also, each plant produces many offspring. Thus, many results can be compared for each type of cross. Recall that collecting repeated data is an important scientific method.

Reading Check ***What is the difference between a trait and a character?***

Figure 2 In the experiments in his garden, Mendel grew and studied many kinds of pea plants. **Why did Mendel study pea plants?**

Seven Characters with Contrasting Traits Studied by Mendel

Flower color	Seed color	Seed shape	Pod color	Pod Shape	Flower position	Plant height
 purple	yellow	 round	 green	 smooth	 mid-stem	 tall
 white	 green	 wrinkled	 yellow	 bumpy	 end of stem	 short

go.hrw.com
interact online
Keyword: HX8GENF3

Three Steps of Mendel's First Experiments

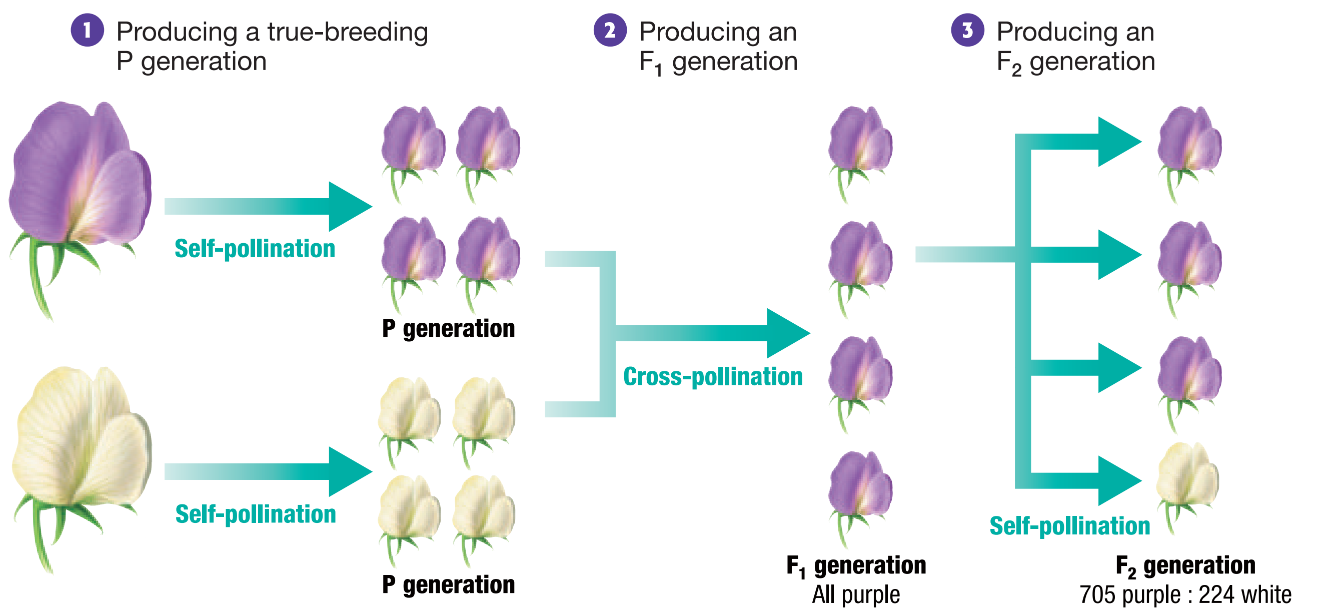


Figure 3 In his garden experiments, Mendel carefully selected and grew specific kinds of pea plants. **❯ What is the relationship between each generation in these experiments?**

Mendel's First Experiments

A *monohybrid cross* is a cross that is done to study one pair of contrasting traits. For example, crossing a plant that has purple flowers with a plant that has white flowers is a monohybrid cross. **❯ Mendel's first experiments used monohybrid crosses and were carried out in three steps.** The three steps are shown in **Figure 3.** Each step involved a new generation of plants. A **generation** is a group of offspring from a given group of parents.

Step 1 Mendel allowed plants that had each type of trait to self-pollinate for several generations. This process ensured that each plant always produced offspring of the same type. Such a plant is said to be *true-breeding* for a given trait. For example, every time a true-breeding plant that has purple flowers self-pollinates, its offspring will have purple flowers. Mendel used true-breeding plants as the first generation in his experiments. The first group of parents that are crossed in a breeding experiment are called the *parental generation,* or *P generation.*

Step 2 Mendel crossed two P generation plants that had contrasting traits, such as purple flowers and white flowers. He called the offspring of the P generation the *first filial generation,* or *F_1 generation*. He recorded the number of F_1 plants that had each trait.

Step 3 Mendel allowed the F_1 generation to self-pollinate and produce new plants. He called this new generation of offspring the *second filial generation,* or *F_2 generation*. He recorded the number of F_2 plants that had each trait.

❯ Reading Check ***What is a monohybrid cross?***

READING TOOLBOX

Word Parts The word *filial* is from the Latin *filialis,* which means "of a son or daughter." Thus, F (filial) generations are all of the generations that follow a P (parental) generation. What do you think *filiation* means?

Data

QuickLab

10 min

Mendel's Ratios

You can calculate and compare the F_2 generation ratios that Mendel obtained from his first experiments.

Procedure

1. Copy this partially complete table onto a separate **sheet of paper**. Then, fill in the ratios of F_2 traits.
2. Simplify the ratios, and round the terms in each ratio to the nearest hundredth digit.

Character	Traits in F_2 generation		Ratio
Flower color	705 purple	224 white	705:224 or 3.15:1.00
Seed color	6,022 yellow	2,001 green	
Seed shape	5,474 round	1,850 wrinkled	
Pod color	428 green	152 yellow	
Pod shape	882 smooth	299 bumpy	
Flower position	651 mid-stem	207 end of stem	
Plant height	787 tall	277 short	

Analysis

1. **Identify** the similarities between the ratios by rounding each term to the nearest whole number.
2. CRITICAL THINKING **Analyzing Data** Why weren't all of the ratios exactly the same?

SCILINKS.
www.scilinks.org
Topic: Gregor Mendel
Code: HX80698

Ratios in Mendel's Results

All of Mendel's F_1 plants expressed the same trait for a given character. The contrasting trait had disappeared! But when the F_1 plants were allowed to self-pollinate, the missing trait reappeared in some of the F_2 plants. Noticing this pattern, Mendel compared the ratio of traits that resulted from each cross.

When F_1 plants that had purple flowers were crossed with one another, 705 of the F_2 offspring had purple flowers and 224 had white flowers. So, the F_2 ratio of purple-flowered plants to white-flowered plants was 705:224, or about 3:1. Mendel's studies of the other characters gave a similar pattern. **For each of the seven characters that Mendel studied, he found a similar 3-to-1 ratio of contrasting traits in the F_2 generation.** As you will learn, Mendel tried to explain this pattern.

Reading Check *What was the important difference between Mendel's F_1 and F_2 generations?*

Section 1 Review

KEY IDEAS

1. **Identify** Gregor Mendel's contribution to modern genetics.
2. **Describe** why garden pea plants are good subjects for genetic experiments.
3. **Summarize** the three major steps of Mendel's first experiments.
4. **State** the typical ratio of traits in Mendel's first experiments.

CRITICAL THINKING

5. **Using Scientific Methods** Why did Mendel record the results of so many plant crosses?
6. **Predicting Outcomes** Squash plants do not usually self-pollinate. If Mendel had used squash plants, how might his experiments have differed?

WRITING FOR SCIENCE

7. **Technical Writing** Imagine that you are Gregor Mendel and you need to document your first experiments for a science magazine. Write out your procedure for breeding pea plants. Be sure to explain how you controlled variables and assured that data was reliable.

Section 2

Mendel's Theory

Key Ideas	Key Terms	Why It Matters
❯ What patterns of heredity were explained by Mendel's hypotheses? ❯ What is the law of segregation? ❯ How does genotype relate to phenotype? ❯ What is the law of independent assortment?	**allele** **dominant** **recessive** **genotype** **phenotype** **homozygous** **heterozygous**	Mendel's theory explains why you have some, but not all, of the traits of your parents.

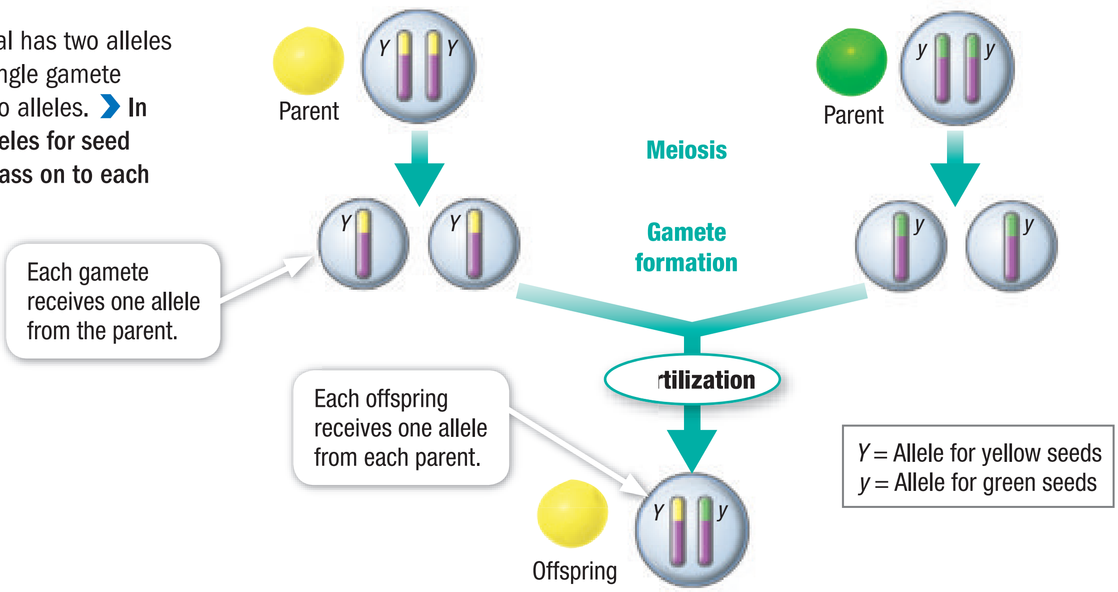
Explaining Mendel's Results

Mendel developed several hypotheses to explain the results of his experiments. His hypotheses were basically correct but have been updated with newer terms and more-complete knowledge. Mendel's hypotheses, collectively called the *Mendelian theory of heredity,* form the foundation of modern genetics. ❯ **Mendelian theory explains simple patterns of inheritance. In these patterns, two of several versions of a gene combine and result in one of several possible traits.**

Alternate Versions of Genes Before Mendel's experiments, many people thought that the traits of offspring were always a blend of the traits from parents. If this notion were true, a tall plant crossed with a short plant would result in offspring of medium height. But Mendel's results did not support the blending hypothesis. Mendel noticed that his pea plants would express only one of two traits for each character, such as purple or white flower color. Today, scientists know that different traits result from different versions of genes. Each version of a gene is called an **allele.**

❯ **Reading Check** ***What is the "blending" hypothesis?***

Figure 4 Each individual has two alleles for a given character. A single gamete carries only one of the two alleles. ❯ **In pea plants, how many alleles for seed color does each parent pass on to each offspring?**



Data

QuickLab

15 min

Dominant and Recessive Traits

Can you find Mendelian patterns in humans? Look for ratios between these contrasting traits.

Procedure

1. On a separate **sheet of paper,** draw a table like the one shown here. For each character, circle the trait that best matches your own trait.
2. Tally the class results to determine how many students in your class share each trait.

Dominant trait	Recessive trait
freckles	no freckles
no cleft	cleft chin
dimples	no dimples

Analysis

1. **Summarize** the class results for each character.
2. **Calculate** the ratio of dominant traits to recessive traits for each character.
3. CRITICAL THINKING **Mathematical Reasoning** Are each of the ratios the same? Why is this unlikely to happen?
4. CRITICAL THINKING **Analyzing Results** For which traits must a person who has the given trait receive the same allele from both parents? Explain your answer.

One Allele from Each Parent Mendel also noticed that traits can come from either parent. The reason is related to meiosis, as **Figure 4** shows. When gametes form, each pair of alleles is separated. Only one of the pair is passed on to offspring.

Dominant and Recessive Alleles For every pair of traits that Mendel studied, one trait always seemed to "win" over the other. That is, whenever both alleles were present, only one was fully expressed as a trait. The other allele had no effect on the organism's physical form. In this case, the expressed allele is called **dominant.** The allele that is not expressed when the dominant allele is present is called **recessive.** Traits may also be called *dominant* or *recessive*. For example, in pea plants, the yellow-seed trait is dominant, and the green-seed trait is recessive.

allele (uh LEEL) one of two or more alternative forms of a gene, each leading to a unique trait

dominant (DAHM uh nuhnt) describes an allele that is fully expressed whenever the allele is present in an individual

recessive (ri SES iv) describes an allele that is expressed only when there is no dominant allele present in an individual

Random Segregation of Alleles

Mendel did not understand how chromosomes separate during meiosis, but he learned something important about this process. Because chromosome pairs split up randomly, either one of a pair of homologous chromosomes might end up in any one gamete. As **Figure 4** shows, offspring receive one allele from each parent. But only chance decides which alleles will be passed on through gametes. Mendel showed that segregation is random, and he stated his hypothesis as a law. **In modern terms, the *law of segregation* holds that when an organism produces gametes, each pair of alleles is separated and each gamete has an equal chance of receiving either one of the alleles.**

ACADEMIC VOCABULARY

random without aim

Mendel's Findings in Modern Terms

Although Mendel did not use the term allele, he used a code of letters to represent the function of alleles. Today, scientists use such a code along with modern terms, as shown in **Figure 5.** A dominant allele is shown as a capital letter. This letter is usually the first letter of the word for the trait. For example, purple flower color is a dominant trait in pea plants, so the allele is written as *P*. A recessive allele is shown as a lowercase letter. The letter is usually the same as the one used for the dominant allele. So, white flower color is written as *p*.

Genotype and Phenotype Mendel's experiments showed that an offspring's traits do not match one-to-one with the parents' traits. In other words, offspring do not show a trait for every allele that they receive. Instead, combinations of alleles determine traits. The set of alleles that an individual has for a character is called the **genotype.** The trait that results from a set of alleles is the **phenotype.** In other words, **genotype determines phenotype.** For example, if the genotype of a pea plant is *pp,* the phenotype is white flowers. If the genotype is *Pp* or *PP,* the phenotype is purple flowers, as shown in **Figure 5.**

READING TOOLBOX

Word Parts Look up the word *phenomenon* in a dictionary. What is the meaning of the Greek root of this word? How does this meaning apply to the word *phenotype* as used in biology?

genotype (JEE nuh TIEP) a specific combination of alleles in an individual

phenotype (FEE noh TIEP) the detectable trait or traits that result from the genotype of an individual

homozygous (HOH moh ZIE guhs) describes an individual that carries two identical alleles of a gene

heterozygous (HET uhr OH ZIE guhs) describes an individual that carries two different alleles of a gene

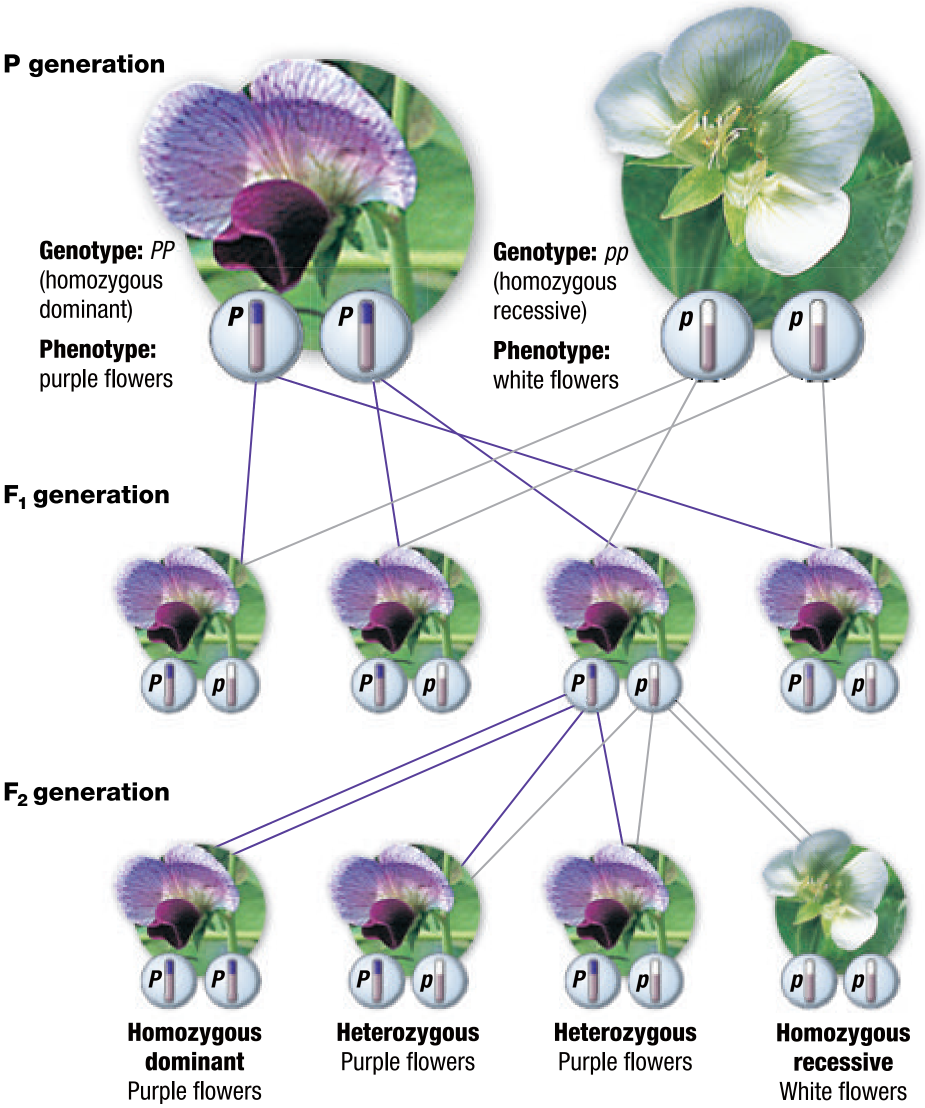


Figure 5 Mendel's first experiments demonstrated dominance, segregation, genotype, and phenotype. **What is the relationship between the genotypes and phenotypes in each generation shown here?**

Homozygous and Heterozygous If an individual has two of the same alleles of a certain gene, the individual is **homozygous** for the related character. For example, a plant that has two white-flower alleles (*pp*) is homozygous for flower color. On the other hand, if an individual has two different alleles of a certain gene, the individual is **heterozygous** for the related character. For example, a plant that has one purple-flower allele and one white-flower allele (*Pp*) is heterozygous for flower color. In the heterozygous case, the dominant allele is expressed. This condition explains Mendel's curious results, as **Figure 5** shows.

Mendel's Second Experiments

Mendel not only looked for patterns, he also looked for a lack of patterns. For example, the round-seed trait did not always show up in garden pea plants that had the yellow-seed trait. Mendel made dihybrid crosses to study these results. A *dihybrid cross,* shown in **Figure 6,** involves two characters, such as seed color and seed shape.

Independent Assortment In these crosses, Mendel found that the inheritance of one character did not affect the inheritance of any other. He proposed another law. **In modern terms, the *law of independent assortment* holds that during gamete formation, the alleles of each gene segregate independently.** For example, in **Figure 6,** the alleles for seed color (*Y* and *y*) can "mix and match" with the alleles for seed shape (*R* and *r*). So, round seeds may or may not be yellow.

Genes Linked on Chromosomes Mendel's second law seems to say that each gene has nothing to do with other genes. But we now know that many genes are linked to each other as parts of chromosomes. So, genes that are located close together on the same chromosome will rarely separate independently. Thus, genes are said to be *linked* when they are close together on chromosomes. The only genes that follow Mendel's law are those that are far apart.

Reading Check *What is a dihybrid cross?*

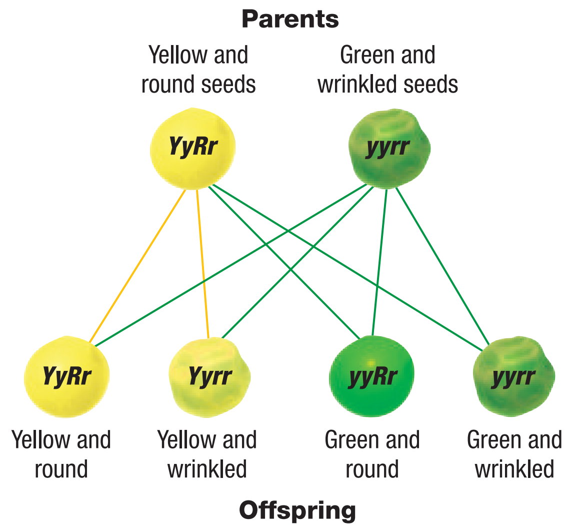


Figure 6 Mendel used dihybrid crosses in his second experiments. He found that the inheritance of one character, such as seed color, did not affect the inheritance of another character, such as seed shape.
What law did Mendel propose to explain these findings?

SCILINKS. www.scilinks.org
Topic: Mendel's Laws
Code: HX80938

Section 2 Review

KEY IDEAS

1. **Describe** the patterns that Mendelian theory explains.
2. **Summarize** the law of segregation.
3. **Relate** genotype to phenotype, using examples from Mendel's experiments with pea plants.
4. **Summarize** the law of independent assortment.

CRITICAL THINKING

5. **Analyzing Data** The term *gene* did not exist when Mendel formed his hypotheses. What other genetic terms are used today that Mendel did not likely use?
6. **Arguing Logically** Would it be correct to say that a genotype is heterozygous recessive? Explain.
7. **Critiquing Explanations** Identify the strengths and weaknesses of Mendel's law of independent assortment.

METHODS OF SCIENCE

8. **Testing an Hypothesis** How did Mendel test his hypothesis that the inheritance of one character does not affect the inheritance of another character?

Section 3

Modeling Mendel's Laws

Key Ideas	Key Terms	Why It Matters
How can a Punnett square be used in genetics? How can mathematical probability be used in genetics? What information does a pedigree show?	Punnett square probability pedigree genetic disorder	Mendel's laws can be used to help breed exotic pets, thoroughbred livestock, and productive crops.

Why are Mendel's laws so important? Mendel's laws can be used to predict and understand the results of certain kinds of crosses. Farmers, gardeners, animal keepers, and biologists need to make predictions when they try to breed organisms that have desired character. Medical professionals need to know about the inheritance of traits in their patients. Graphical models that can help with these tasks include Punnett squares and pedigrees.

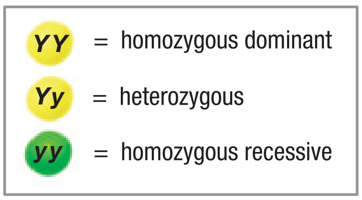
Using Punnett Squares

A **Punnett square** is a model that predicts the likely outcomes of a genetic cross. The model is named for its inventor, Reginald Punnett. **A Punnett square shows all of the genotypes that could result from a given cross.**

The simplest Punnett square consists of a square divided into four boxes. As **Figure 7** shows, the possible alleles from one parent are written along the top of the square. The possible alleles from the other parent are written along the left side. Each box inside the square holds two letters. The combination of letters in each box represents one possible genotype in the offspring. The letters in each box are a combination of two alleles—one from each parent.

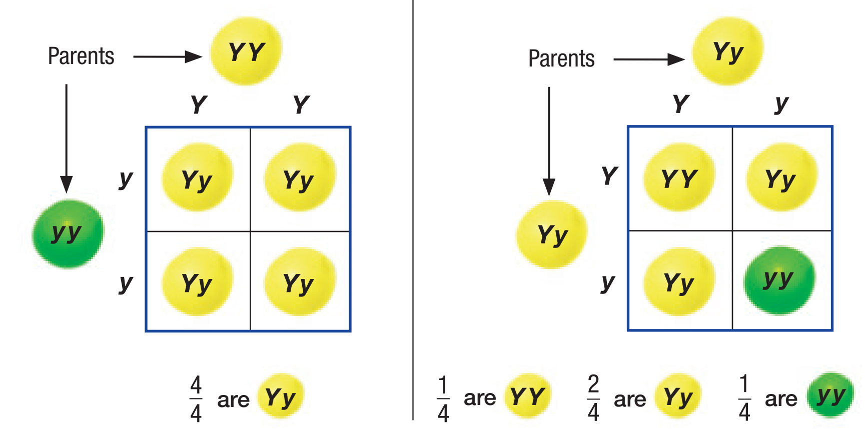
Punnett square (PUHN uht SKWER) a graphic used to predict the results of a genetic cross

Figure 7 Each of these Punnett squares shows a monohybrid cross involving seed color in peas. **How does a Punnett square predict the outcome of a cross?**



Homozygous Cross In a cross of homozygous parents that have contrasting traits, 100% of the offspring will be heterozygous and will show the dominant trait.

Heterozygous Cross In a cross of heterozygous parents that have the same traits, the ratio of genotypes will be 1:2:1. The ratio of phenotypes will be 3:1.



Data

QuickLab

10 min

Testcross

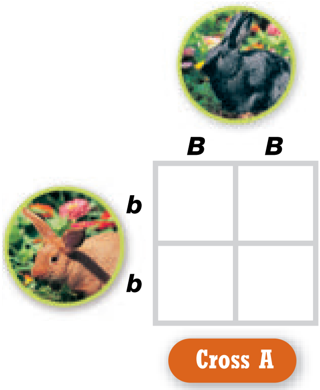
When genotypes are known, Punnett squares can be used to predict phenotypes. But can genotypes be determined if only phenotypes are known?

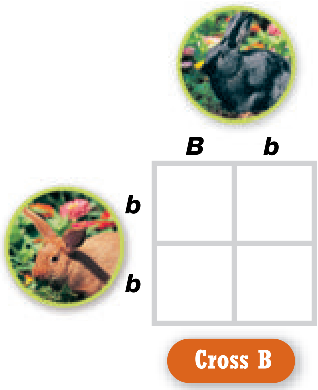
Suppose a breeder has a rabbit that has a dominant phenotype, such as black fur (as opposed to recessive brown fur). How could the breeder know whether the rabbit is homozygous (*BB*) or heterozygous (*Bb*) for fur color? The breeder could perform a testcross.

A *testcross* is used to test an individual whose phenotype for a characteristic is dominant but whose genotype is not known. This individual is crossed with an individual whose genotype is known to be homozygous recessive. In our example, the breeder would cross the black rabbit (*BB* or *Bb*) with a brown rabbit (*bb*).

Procedure

On a separate **sheet of paper,** copy the two Punnett squares shown here. Write the appropriate letters in the boxes of each square.





Analysis

1. **Label** what each pair of letters represents in each of the Punnett squares.
2. **Identify** which figure represents a testcross involving a heterozygous parent.
3. **Identify** which figure shows a cross in which all offspring will have black fur.
4. CRITICAL THINKING **Applying Models** If half of the offspring in a testcross have brown fur, what is the genotype of the parent that has black fur?

Analyzing Monohybrid Crosses Two kinds of monohybrid crosses are shown in **Figure 7.** A simple Punnett square can be used to analyze a monohybrid cross. Recall that this cross involves parents who each have a trait that contrasts with the trait of the other parent. The parents may be homozygous or heterozygous.

Monohybrid Homozygous Crosses Consider a cross between a pea plant that is homozygous for yellow seed color (*YY*) and a pea plant that is homozygous for green seed color (*yy*). The first Punnett square in **Figure 7** shows that all of the offspring in this type of cross will be heterozygous (*Yy*) and will express the dominant trait of yellow seed color. Other results are not possible in this case.

Monohybrid Heterozygous Crosses The second Punnett square in **Figure 7** predicts the results of a monohybrid cross between two pea plants that are heterozygous (*Yy*) for seed color. This cross is more complex than a homozygous cross. About one-fourth of the offspring will be *YY*. About two-fourths (or one-half) will be *Yy*. And about one-fourth will be *yy*. Another way to express this prediction is to say that the genotypic ratio will be 1 *YY* : 2 *Yy* : 1 *yy*. Because the *Y* allele is dominant, three-fourths of the offspring will be yellow (*YY* or *Yy*) and one-fourth will be green (*yy*). Thus, the phenotypic ratio will be 3 yellow : 1 green.

› **Reading Check** *Explain the boxes inside a Punnett square?*

ACADEMIC VOCABULARY

contrast different when compared

READING TOOLBOX

Analogies Use the information on this page to solve the following analogy.

yy : Yy :: Homozygous : _______

Data

QuickLab

15 min

Probabilities

Some people are born with extra fingers or toes. This condition, known as *polydactyly,* is rare. However, it is usually the result of a dominant allele.

Procedure

Draw Punnett squares to represent all possible combinations of alleles for each the crosses discussed below. Use *Z* to represent a dominant allele and *z* to represent a recessive allele.

Analysis

1. **Calculate** the probability that a cross of two heterozygous (*Zz*) parents will produce homozygous dominant (*ZZ*) offspring.
2. **Determine** the probability that a cross of a heterozygous parent (Zz) and a homozygous recessive *(zz)* parent will produce heterozygous offspring.
3. **Calculate** the probability that a cross of a homozygous dominant parent and a homozygous recessive parent will produce heterozygous offspring.
4. **Determine** the probability that a cross between a heterozygous parent and a homozygous recessive parent will produce homozygous dominant offspring.

▲ Polydactyly (extra fingers or toes) is usually a dominant trait.

Using Probability

Punnett squares allow direct and simple predictions to be made about the outcomes of genetic crosses, but those predictions are not certain. A Punnett square shows the possible outcomes of a cross, but it can also be used to calculate the probability of each outcome. **Probability** is the likelihood that a specific event will occur.

Academic Vocabulary

occur to take place

Calculating Probability Punnett squares are one simple way to demonstrate probability. Probability can be calculated and expressed in many ways. Probability can be expressed in words, as a decimal, as a percentage, or as a fraction. For example, if an event will definitely occur, its probability can be expressed as either 1 out of 1 (in words), 100 % (as a percentage), 1.0 (as a decimal), or $\frac{1}{1}$ (as a fraction). If an event is just as likely to occur as to not occur, its probability can be expressed as either 1 out of 2, 50 %, 0.5, or $\frac{1}{2}$. Probability can be determined by the following formula:

$$\text{probability} = \frac{\text{number of one kind of possible outcome}}{\text{total number of all possible outcomes}}$$

probability (PRAHB uh BIL uh tee) the likelihood that a specific event will occur; expressed in mathematical terms

Consider the example of a coin tossed into the air. The total number of possible outcomes is two—heads or tails. Landing on heads is one possible outcome. Thus, the probability that the coin will land on heads is $\frac{1}{2}$. Likewise, the probability that it will land on tails is $\frac{1}{2}$. Of course, the coin will not land on tails exactly half of the time, but it will tend to do so. The average number of total flips that result in tails will tend to be $\frac{1}{2}$.

Probability of a Specific Allele in a Gamete Recall the law of segregation, which states that each gamete has an equal chance of receiving either one of a pair of alleles. If a pea plant has two alleles for seed color, only one of the two alleles (yellow or green) can end up in a gamete. **Probability formulas can be used to predict the probabilities that specific alleles will be passed on to offspring.** For a plant that has two alleles for seed color, the total number of possible outcomes is two—green or yellow. The probability that a gamete from this plant will carry the allele for green seed color is $\frac{1}{2}$. The probability that a gamete will carry the allele for yellow seed color is also $\frac{1}{2}$.

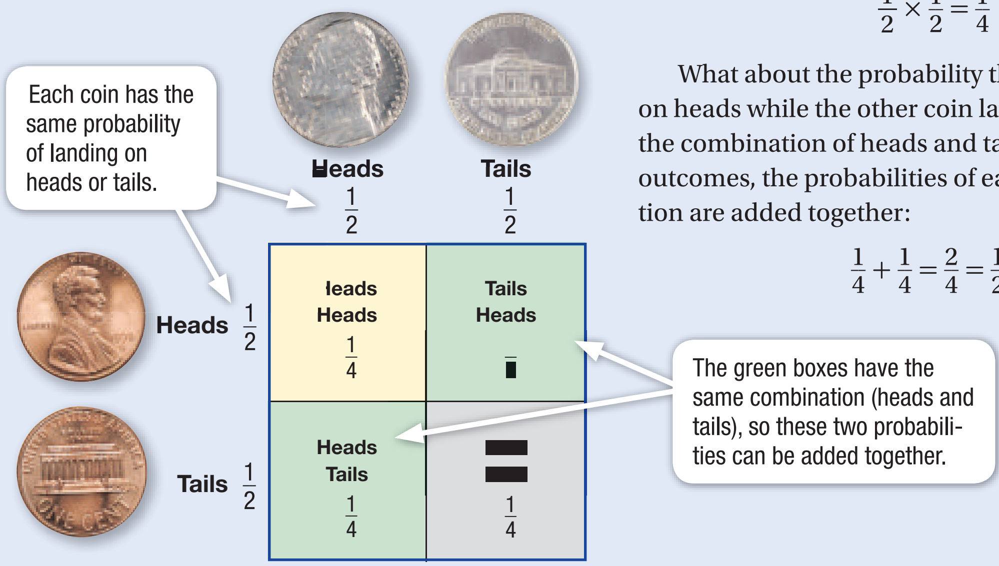
Probability in a Heterozygous Cross The possible results of a heterozygous cross are similar to those of flipping two coins at once. Consider the possible results of a cross of two pea plants that are heterozygous for seed shape (*Rr*). Either parent is equally likely to pass on a gamete that has either an *R* allele or an *r* allele. So, the chance of inheriting either allele is $\frac{1}{2}$. Multiplying the probabilities for each gamete shows that the probability that the offspring will have *RR* alleles is $\frac{1}{4}$. The probability that the offspring will have *rr* alleles is also $\frac{1}{4}$. The combination *Rr* has two possible outcomes, so the probability that the offspring will have *Rr* alleles is $\frac{2}{4}$, or $\frac{1}{2}$.

Reading Check ***What is the probability that a heterozygous cross will produce homozygous recessive offspring?***

SCILINKS
www.scilinks.org
Topic: Probability
Code: HX81217

Math Skills — Probability of Two Independent Events

Because two parents are involved in a genetic cross, both parents must be considered when predicting the probable outcomes. Consider the example of tossing two coins at the same time. The probability that a penny will land on heads is $\frac{1}{2}$, and the probability that a nickel will land on heads is $\frac{1}{2}$. How one coin falls does not affect how the other coin falls.



What is the probability that the nickel and the penny will both land on heads at the same time? To find the probability that a specific combination of two independent events will occur, multiply the probabilities of each event. Thus, the probability that both coins will land on heads is

$$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$$

What about the probability that one coin will land on heads while the other coin lands on tails? Because the combination of heads and tails has two possible outcomes, the probabilities of each possible combination are added together:

$$\frac{1}{4} + \frac{1}{4} = \frac{2}{4} = \frac{1}{2}$$

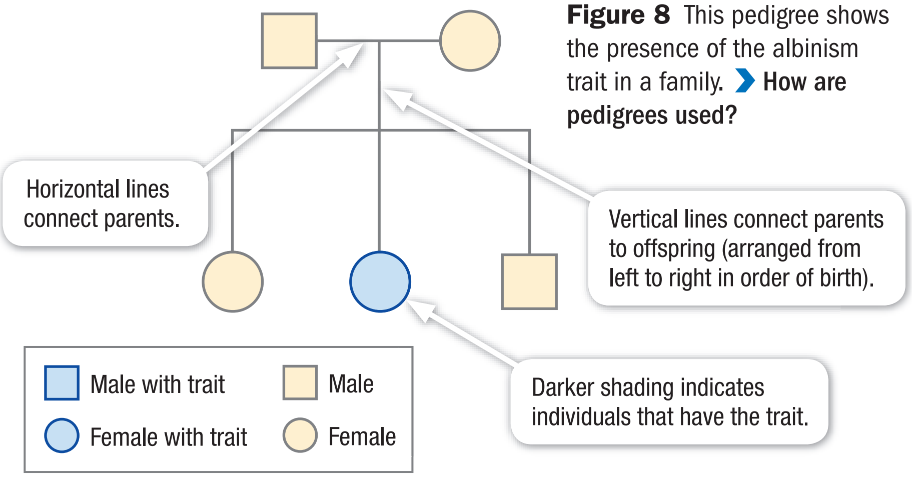


Figure 8 This pedigree shows the presence of the albinism trait in a family. **How are pedigrees used?**

Figure 8 Albinism is a genetic disorder carried by a recessive allele. Because of this disorder, this baby koala's skin and hair cells do not produce pigments, so the baby is mostly white. In the wild, albino animals have little chance of survival.

Using a Pedigree

Mendel observed several generations of pea plants to see patterns in the inheritance of traits. A simple way to model inheritance is to use a pedigree. A **pedigree** is a family history that shows how a trait is inherited over several generations. A healthcare worker may use a pedigree to help a family understand a genetic disorder. A **genetic disorder** is a disease or disorder that can be inherited. If a family has a history of a genetic disorder, the parents may want to know if their children could inherit the disorder. Some parents are carriers. Carriers have alleles for a disorder but do not show symptoms. Carriers can pass the allele for the disorder to their offspring.

Figure 8 shows a pedigree for a family in which albinism is present. A body affected by the genetic disorder albinism is unable to produce the pigment that gives dark color to skin, eyes, and hair. Without this pigment, the body may appear white or pink, as **Figure 9** shows. A recessive allele causes albinism. The pedigree helps show how this trait is inherited. **A pedigree can help answer questions about three aspects of inheritance: sex linkage, dominance, and heterozygosity.**

Sex-Linked Gene The sex chromosomes, X and Y, carry genes for many characters other than gender. A *sex-linked gene* is located on either an X or a Y chromosome, but most are located on the X chromosome. Because it is much shorter than the X chromosome, the Y chromosome holds fewer genes. Females have two X chromosomes. A recessive allele on one of the X chromosomes will often have a corresponding dominant allele on the other. Thus, the trait for the recessive allele is not expressed in the female. Males, on the other hand, have an X chromosome and the much shorter Y chromosome. Because it has few genes, the shorter Y chromosome may lack an allele that corresponds to a recessive allele on the longer X chromosome. So, the trait for the single recessive allele will be expressed in the male. Traits that are not expressed equally in both sexes are commonly sex-linked traits. Colorblindness is an example of a sex-linked trait that is expressed more in males than in females.

Reading Check *How can one identify a sex-linked trait?*

pedigree (PED i GREE) a diagram that shows the occurrence of a genetic trait in several generations of a family

genetic disorder an inherited disease or disorder that is caused by a mutation in a gene or by a chromosomal defect

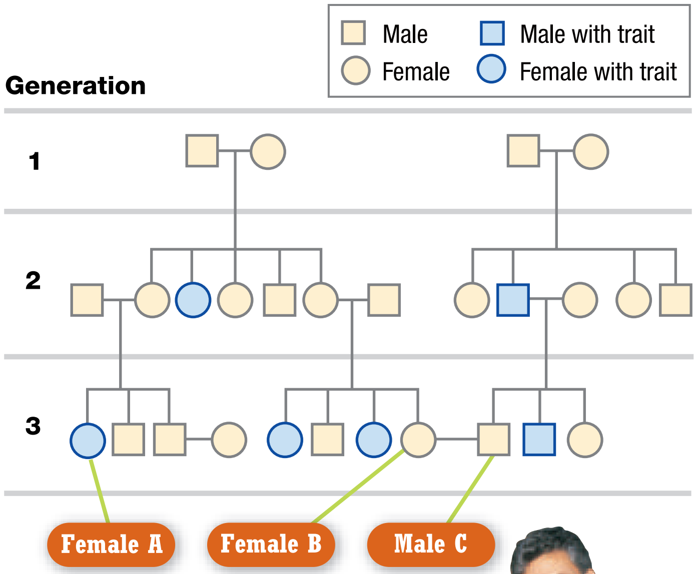
Data

QuickLab

15 min

Pedigree Analysis

You will practice interpreting a pedigree. The pedigree to the right shows the presence or absence of the albinism trait in several generations of a family.

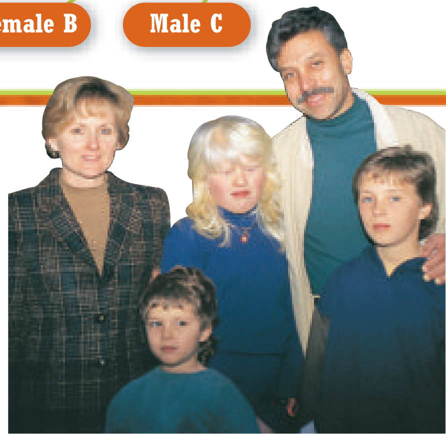


Analysis

1. **Determine** whether the albinism trait is dominant or recessive. Explain your reasoning.
2. **Determine** if Female A could be heterozygous for albinism. Do the same for Female B.
3. CRITICAL THINKING **Applying Information** Suppose that Female B is homozygous and produces children with Male C. If Male C is heterozygous, what is the probability that the children will have the albinism trait?

Dominant or Recessive? If a person has a trait that is autosomal and dominant and has even one dominant allele, he or she will show the trait. A dominant allele is needed to pass on the trait. If a person has a recessive trait and only one recessive allele, he or she will not show the trait but may pass it on. So, if a trait appears in a child whose parents lack the trait, it is most likely recessive.

Heterozygous or Homozygous? If a person is either heterozygous or homozygous dominant for an autosomal gene, his or her phenotype will show the dominant trait. If a person is homozygous recessive, his or her phenotype will show the recessive trait. Heterozygous parents can produce a child who is homozygous recessive. Thus, a recessive trait in the child shows that both parents were heterozygous carriers of the recessive allele.



This family's daughter has the albinism trait.

Section 3 Review

KEY IDEAS

1. **Describe** how a Punnett square is used in gentics.
2. **List** ways to express mathematical probability in genetics.
3. **Sketch** a pedigree for an imaginary family of three generations and describe what the pedigree shows.

CRITICAL THINKING

4. **Scientific Methods** How can you determine the genotype of a pea plant that has purple flowers?
5. **Mathematical Reasoning** If you flip two coins at once, will at least one coin land on heads? Explain.
6. **Analyzing Graphics** When analyzing a pedigree, how can you determine if an individual is a carrier (heterozygous) for the trait being studied?

USING SCIENCE GRAPHICS

7. **Pedigree** Some kinds of colorblindness are sex-linked traits carried on the X chromosome. So, males can inherit the trait from mothers that are not colorblind. Draw a pedigree that demonstrates this pattern of inheritance.

Section 4

Beyond Mendelian Heredity

Key Ideas	Key Terms	Why It Matters
❯ Are there exceptions to the simple Mendelian pattern of inheritance? ❯ How do heredity and the environment interact to influence phenotype? ❯ How do linked genes affect chromosome assortment and crossover during meiosis?	polygenic character codominance linked	Some inheritance is more complex than Mendel showed. This complexity helps explain the large variety of human traits.

Suppose a horse that has red hair mates with a horse that has white hair. The offspring of the horses has both red and white hair on its body. How can this be? Shouldn't the colt's hair be one color or the other? Not always! In fact, most characters are not inherited in the simple patterns identified by Mendel. Although Mendel was correct about the inheritance of the traits that he studied, most patterns of inheritance are more complex than those that Mendel identified.

Many Genes, Many Alleles

If you look at people and animals around you, you will notice a variety of physical features, as **Figure 9** shows. Why do so few of these features have only two types? First, not all genes have only two alleles. Second, not all characters are controlled by one gene. ❯ **The Mendelian inheritance pattern is rare in nature; other patterns include polygenic inheritance, incomplete dominance, multiple alleles, and codominance.**

Polygenic Inheritance When several genes affect a character, it is called a **polygenic character.** For example, eye color is affected by several genes. One gene controls the relative amount of greenness of the eye, and another gene controls brownness. (The recessive condition in both cases is blue eyes.) Other genes also affect eye color. Sorting out the effects of each gene is difficult. The genes may be on the same or different chromosomes. Other examples of polygenic characters in humans are height and skin color. In fact, most characters are polygenic.

Incomplete Dominance Recall that in Mendel's pea-plant crosses, one allele was completely dominant over the other. In some cases, however, an offspring has a phenotype that is intermediate between the traits of its two parents. This pattern is called *incomplete dominance*.

Figure 9 A physical feature—such as height, weight, hair color, and eye color—is often influenced by more than one gene.

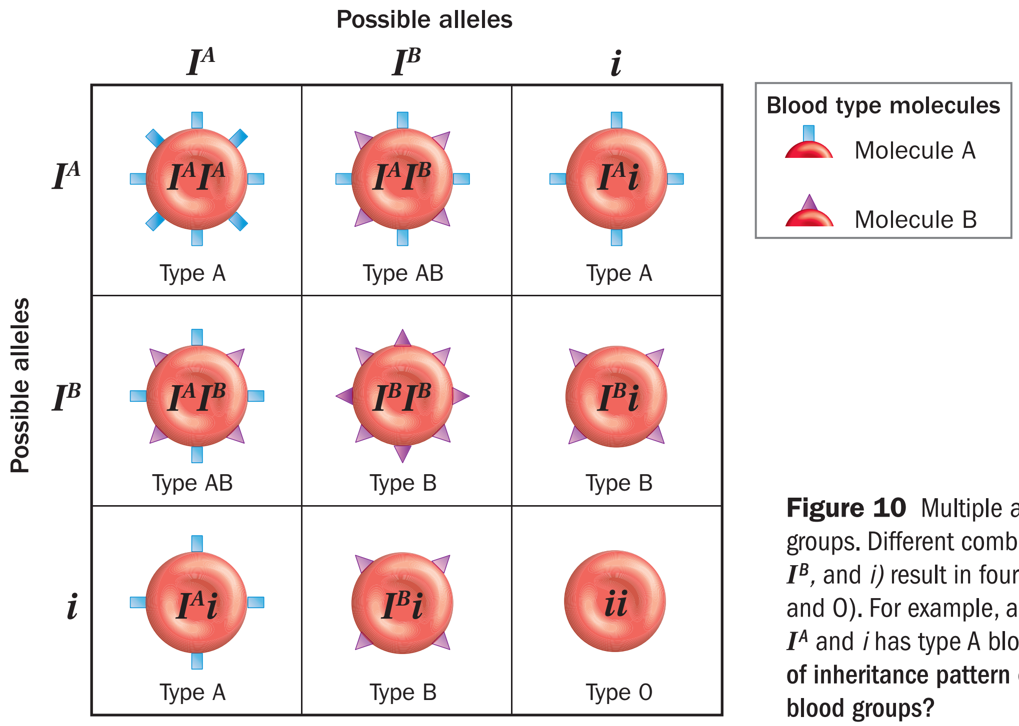


Figure 10 Multiple alleles control the ABO blood groups. Different combinations of three alleles (I^A, I^B, and i) result in four blood phenotypes (A, AB, B, and O). For example, a person who has the alleles I^A and i has type A blood. › **What is another kind of inheritance pattern demonstrated by the ABO blood groups?**

When a snapdragon that has red flowers is crossed with a snapdragon that has white flowers, the offspring have pink flowers. Neither the red allele nor the white allele is completely dominant over the other. The pink flowers simply have less red pigment than the red flowers do.

Multiple Alleles Genes that have three or more possible alleles are said to have *multiple alleles*. For example, multiple alleles exist for hair color in cats. Still, only two alleles for a gene can be present in one individual. The determination of dominance may be complex.

In humans, the ABO blood groups (blood types) are determined by three alleles: I^A, I^B, and i. **Figure 10** shows how various combinations of the three alleles can produce four blood types: A, B, AB, and O. The I^A and I^B alleles cause red blood cells to make certain molecules. The letters *A* and *B* refer to the two kinds of molecules. The *i* allele does not cause either molecule to be made. So, both the I^A and I^B alleles are dominant over *i*. But I^A and I^B are not dominant over each other. So, a person who has both I^A and I^B alleles has type AB blood. A person who has two *i* alleles has type O blood.

Codominance For some characters, two traits can appear at the same time. **Codominance** is a condition in which both alleles for the same gene are fully expressed.

The genetics of human blood groups, which was discussed above, is also an example of codominance. A person who has I^AI^B alleles will have type AB blood because neither allele is dominant over the other. Type AB blood cells make both A-type and B-type molecules.

› **Reading Check** ***How does codominance differ from incomplete dominance?***

polygenic (PAHL uh JEN ik) **character**
a character that is influenced by more than one gene

codominance (KOH DAHM uh nuhns)
a condition in which both alleles for a gene are fully expressed

ACADEMIC VOCABULARY

various many kinds of

SCILINKS.
www.scilinks.org
Topic: Mendelian Genetics
Code: HX80940

Figure 11 Many Arctic mammals, such as the Arctic fox, develop white fur during the winter and dark fur during the summer. **What does this change indicate about the character for fur color in these animals?**

linked in genetics, describes two or more genes that tend to be inherited together

Genes Affected by the Environment

Genes are the key to life, but there is more to life than genes. **Phenotype can be affected by conditions in the environment, such as nutrients and temperature.** For example, temperature affects the fur color of the Arctic fox, shown in **Figure 11.** During summer, genes in the fox's skin cells cause pigments to be made. These pigments make the fox's coat darker. Dark fur color helps the fox blend in with grass or woods. But during cold weather, the genes stop causing pigment to be made. Then, the fox's fur grows white, and the fox can blend in with the winter snow.

In humans, many of the characters that are partly determined by heredity are also affected by the environment. For example, a person's height is partly hereditary. Tall parents tend to produce tall children. But nutrition also affects height. A person who has an unhealthy diet may not grow as tall as he or she could have. Many aspects of human personality and behavior are strongly affected by the environment, but genes also seem to play an important role.

Genes Linked Within Chromosomes

Many traits do not follow Mendel's laws, but Mendel's pea traits did. Why? One reason is that Mendel studied the simplest kinds of heredity: characters determined by one gene that has two alleles. Also, he studied characters that are determined by independent genes.

Recall how meiosis relates to the *law of independent assortment*. If genes are on different chromosomes, the alleles for each gene can be sorted independently. Then, each set of alleles can be recombined in any way. For example, in the pea plants, the two alleles for seed color could be combined in any way with the two alleles for seed shape.

Some genes are close together on the same chromosome. **During meiosis, genes that are close together on the same chromosome are less likely to be separated than genes that are far apart.** Genes that are close together, as well as the traits that they determine, are said to be **linked.**

Reading Check ***What term describes genes that are close together on the same chromosome and that are unlikely to be separated?***

Section 4 Review

KEY IDEAS

1. **List** exceptions to the Mendelian pattern of one character controlled by two alleles.
2. **Describe** the relationship between heredity and the environment.
3. **Relate** gene linkage to chromosome assortment and crossover during meiosis.

CRITICAL THINKING

4. **Evaluating an Argument** A classmate states that Mendel's hypotheses are incorrect because they do not consider intermediate forms of a character. Evaluate this argument.
5. **Justifying Conclusions** A classmate states that a person cannot have type BO blood. Do you agree or disagree? Explain your reasoning.

USING SCIENCE GRAPHICS

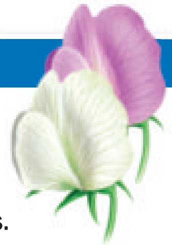
6. **Punnett Square** Predict the ratios of each of the ABO blood groups in an average population. Use a Punnett square like the one shown in Figure 11 and explain your results. Assume that the population has equal numbers of I^A, I^B, and i alleles.

Chapter 12 Summary

go.hrw.com
SUPER SUMMARY
Keyword: HX8GENS

Key Ideas | **Key Terms**

1 Origins of Hereditary Science



- Modern genetics is based on Mendel's explanations for the patterns of heredity that he studied in garden pea plants.
- The garden pea plant is a good subject for studying heredity because the plant has contrasting traits, usually self-pollinates, and grows easily.
- Mendel's first experiments used monohybrid crosses and were carried out in three steps.
- For each of the seven characters that Mendel studied, he found a similar 3-to-1 ratio of contrasting traits in the F_2 generation.

Key Terms

character (268)
trait (268)
hybrid (268)
generation (269)

2 Mendel's Theory

- Mendelian theory explains simple patterns of inheritance in which the combination of two alleles results in one of several possible traits.
- In modern terms, the *law of segregation* holds that when an organism produces gametes, each pair of alleles is separated and each gamete has an equal chance of receiving either one of the alleles.
- Genotype determines phenotype.
- In modern terms, the *law of independent assortment* holds that during gamete formation, the alleles of each gene segregate independently.

Key Terms

allele (272)
dominant (273)
recessive (273)
genotype (274)
phenotype (274)
homozygous (275)
heterozygous (275)

3 Modeling Mendel's Laws

- A Punnett square shows all of the genotypes that could result from a given cross.
- Probability formulas can be used to predict the probabilities that specific alleles will be passed on to offspring.
- A pedigree can help answer questions about three aspects of inheritance: sex linkage, dominance, and heterozygosity.

Key Terms

Punnett square (276)
probability (278)
pedigree (280)
genetic disorder (280)

4 Beyond Mendelian Heredity

- The Mendelian inheritance is rare in nature; other patterns include polygenic inheritance, incomplete dominance, multiple alleles, and codominance.
- Phenotype can be affected by conditions in the environment, such as nutrients and temperature.
- Genes that are close together on the same chromosome are linked.

Key Terms

polygenic character (282)
codominance (283)
linked (284)