

6.5 Traits and Probability

VOCABULARY

Punnett square
monohybrid cross
testcross
dihybrid cross
law of independent assortment
probability

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

MAIN IDEAS

- ▶ Punnett squares illustrate genetic crosses.
- ▶ A monohybrid cross involves one trait.
- ▶ A dihybrid cross involves two traits.
- ▶ Heredity patterns can be calculated with probability.

Connect to Your World

If you have tried juggling, you know it can be a tricky thing. Keeping three flaming torches or clubs in motion at the same time is a challenge. Trying to keep track of what organism has which genotype and which gamete gets which allele can also be a lot to juggle. Fortunately, R. C. Punnett developed a method to keep track of all of the various combinations graphically.

MAIN IDEA

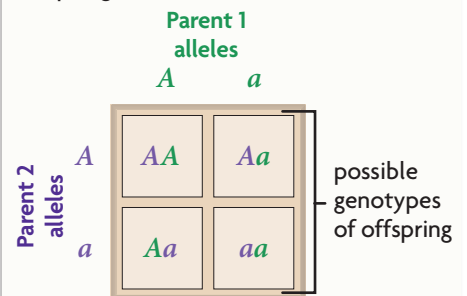
Punnett squares illustrate genetic crosses.

Shortly after Mendel's experiments became widely known among scientists, a poultry geneticist named R. C. Punnett, shown in **FIGURE 5.1**, developed the Punnett square. A **Punnett square** is a grid system for predicting all possible genotypes resulting from a cross. The axes of the grid represent the possible gamete genotypes of each parent. The grid boxes show all of the possible genotypes of offspring from those two parents. Because segregation and fertilization are random events, each combination of alleles is as likely to be produced as any other. By counting the number of squares with each genetic combination, we can find the ratio of genotypes in that generation. If we also know how the genotype corresponds to the phenotype, we can find the ratio of phenotypes in that generation as well.

Let's briefly review what you've learned about meiosis and segregation to examine why the Punnett square is effective. Both parents have two alleles for each gene. These alleles are represented on the axes of the Punnett square. During meiosis, the chromosomes—and, therefore, the alleles—are separated.

VISUAL VOCAB

The **Punnett square** is a grid system for predicting possible genotypes of offspring.



R. C. Punnett

FIGURE 5.1 R. C. Punnett developed the Punnett square as a way to illustrate genetic crosses.

Each gamete gets one of the alleles. Since each parent contributes only one allele to the offspring, only one allele from each parent is written inside each grid box. Fertilization restores the diploid number in the resulting offspring. This is why each grid box has two alleles, one from the mother and one from the father. Since any egg has the same chance of being fertilized by any sperm cell, each possible genetic combination is equally likely to occur.

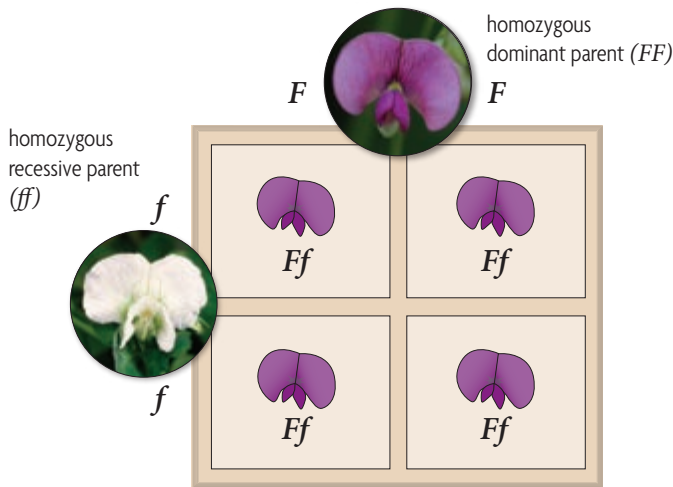
Explain What do the letters on the axes of the Punnett square represent?

MAIN IDEA

A monohybrid cross involves one trait.

Thus far, we have studied **monohybrid crosses**, crosses that examine the inheritance of only one specific trait. Three example crosses are used below and on the next page to illustrate how Punnett squares work and to highlight the resulting ratios—for both genotype and phenotype.

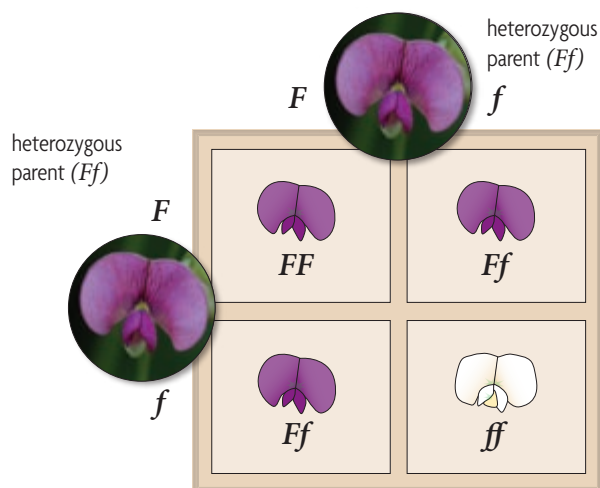
FIGURE 5.2 HOMOZYGOUS-HOMOZYGOUS



Homozygous-Homozygous

Suppose you cross a pea plant that is homozygous dominant for purple flowers with a pea plant that is homozygous recessive for white flowers. To determine the genotypic and phenotypic ratios of the offspring, first write each parent's genotype on one axis: *FF* for the purple-flowered plant, *ff* for the white-flowered plant. Every gamete from the purple-flowered plant contains the dominant allele, *F*. Every gamete from the white-flowered plant contains the recessive allele, *f*. Therefore, 100 percent of the offspring have the heterozygous genotype, *Ff*. And 100 percent of the offspring have purple flowers, because they all have a copy of the dominant allele, as shown in **FIGURE 5.2**.

FIGURE 5.3 HETEROZYGOUS-HETEROZYGOUS



Heterozygous-Heterozygous

Next, in **FIGURE 5.3**, you can see a cross between two purple-flowered pea plants that are both heterozygous (*Ff*). From each parent, half the offspring receive a dominant allele, *F*, and half receive a recessive allele, *f*. Therefore, one-fourth of the offspring have a homozygous dominant genotype, *FF*; half have a heterozygous genotype, *Ff*; and one-fourth have a homozygous recessive genotype, *ff*. Both the *FF* and the *Ff* genotypes result in purple flowers. Only the *ff* genotype results in white flowers. Thus, the genotypic ratio is 1:2:1 of homozygous dominant:heterozygous:homozygous recessive. The phenotypic ratio is 3:1 of purple:white flowers.

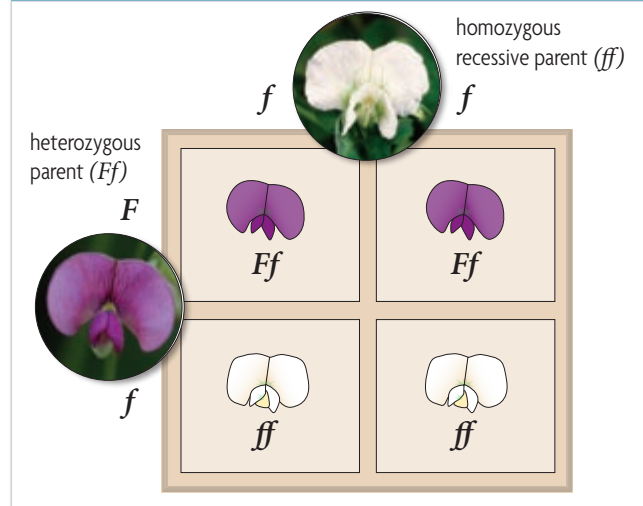
Heterozygous-Homozygous

Finally, suppose you cross a pea plant that is heterozygous for purple flowers (Ff) with a pea plant that is homozygous recessive for white flowers (ff). As before, each parent's genotype is placed on an axis, as shown in **FIGURE 5.4**. From the homozygous parent with white flowers, the offspring each receive a recessive allele, f . From the heterozygous parent, half the offspring receive a dominant allele, F , and half receive a recessive allele, f . Half the offspring have a heterozygous genotype, Ff . Half have a homozygous recessive genotype, ff . Thus, half the offspring have purple flowers, and half have white flowers. The resulting genotypic ratio is 1:1 of heterozygous:homozygous recessive. The phenotypic ratio is 1:1 of purple:white.

Suppose we did not know the genotype of the purple flower in the cross above. This cross would allow us to determine that the purple flower is heterozygous, not homozygous dominant. A **testcross** is a cross between an organism with an unknown genotype and an organism with the recessive phenotype. The organism with the recessive phenotype must be homozygous recessive. The offspring will show whether the organism with the unknown genotype is heterozygous, as above, or homozygous dominant.

Apply From an $FF \times Ff$ cross, what percent of offspring would have purple flowers?

FIGURE 5.4 HETEROZYGOUS-HOMOZYGOUS



QUICK LAB INFERRING

Using a Testcross

Suppose you work for a company that sells plant seeds. You are studying a plant species in which the dominant phenotype is pink flowers (PP or Pp). The recessive phenotype is white flowers (pp). Customers have been requesting more plants with pink flowers. To meet this demand, you need to determine the genotypes of some of the plants you are currently working with.

PROBLEM What is the genotype of each plant?

PROCEDURE

1. Suppose you are presented with Plant A of the species you are studying. It has pink flowers. You want to determine the genotype of the plant.
2. You cross Plant A with Plant B of the same species. This plant has white flowers and a known genotype of pp .
3. The resulting cross yields six plants with pink flowers and six plants with white flowers. Use Punnett squares to determine the genotype of Plant A.

ANALYZE AND CONCLUDE

1. **Apply** What is the genotype of Plant A? Explain how you arrived at your answer.
2. **Apply** What are the possible genotypes and phenotypes of offspring if Plant A is crossed with a plant that has a genotype of PP ?
3. **Calculate** What ratio of dominant to recessive phenotypes would exist if Plant A were crossed with a plant that has a genotype of Pp ?
4. **Evaluate** Is Plant A the best plant, in terms of genotype, that you can work with to produce as many of the requested seeds as possible? Why or why not? Which genotype would be best to work with?

MATERIALS

- pencil
- paper

MAIN IDEA

A dihybrid cross involves two traits.

CONNECT TO

LAW OF SEGREGATION

As you learned in **Section 3**, Mendel's first law of inheritance is the law of segregation. It states that organisms inherit two copies of each gene but donate only one copy to each gamete.



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PREMIUM CONTENT

Law of Independent Assortment

All of the crosses discussed so far have involved only a single trait. However, Mendel also conducted **dihybrid crosses**, crosses that examine the inheritance of two different traits. He wondered if both traits would always appear together or if they would be expressed independently of each other.

Mendel performed many dihybrid crosses and tested a variety of different combinations. For example, he would cross a plant with yellow round peas with a plant with green wrinkled peas. Remember that Mendel began his crosses with purebred plants. Thus, the first generation offspring (F_1) would all be heterozygous and would all look the same. In this example, the plants would all have yellow round peas. When Mendel allowed the F_1 plants to self-pollinate, he obtained the following results: 9 yellow/round, 3 yellow/wrinkled, 3 green/round, 1 green/wrinkled.

Mendel continued to find this approximately 9:3:3:1 phenotypic ratio in the F_2 generation, regardless of the combination of traits. From these results, he realized that the presence of one trait did not affect the presence of another trait. His second law of genetics, the **law of independent assortment**, states that allele pairs separate independently of each other during gamete formation, or meiosis. That is, different traits appear to be inherited separately.

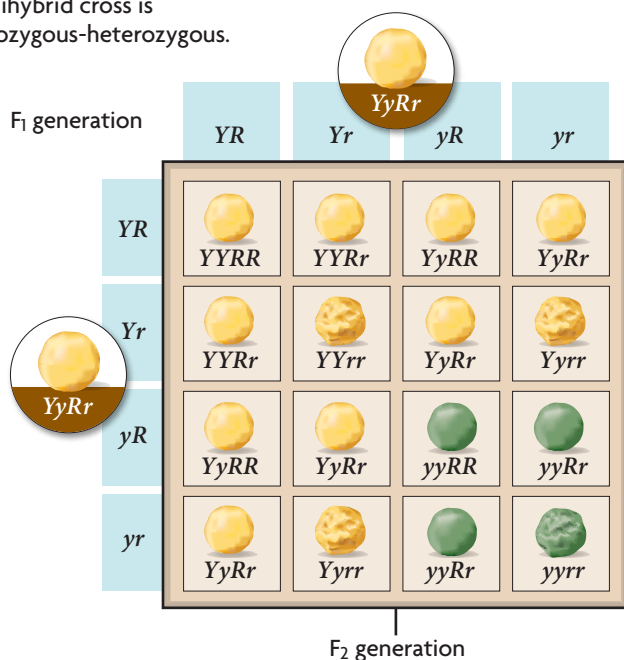
The results of Mendel's dihybrid crosses can also be illustrated with a Punnett square, like the one in **FIGURE 5.5**. Drawing a Punnett square for a dihybrid cross is the same as drawing one for a monohybrid cross, except that the grid is bigger because two genes, or four alleles, are involved. For example, suppose you cross two plants with yellow, round peas that are heterozygous for both traits ($YyRr$). The four allele combinations possible in each gamete—

YR , Yr , yR , and yr —are used to label each axis. Each grid box can be filled in using the same method as that used in the monohybrid cross. A total of nine different genotypes may result from the cross in this example. However, these nine genotypes produce only four different phenotypes. These phenotypes are yellow round, yellow wrinkled, green round, and green wrinkled, and they occur in the ratio of 9:3:3:1. Note that the 9:3:3:1 phenotypic ratio results from a cross between organisms that are heterozygous for both traits. The phenotypic ratio of the offspring will differ (from 9:3:3:1) if one or both of the parent organisms are homozygous for one or both traits.

Analyze In **FIGURE 5.5**, the boxes on the axes represent the possible gametes made by each parent plant. Why does each box have two alleles?

FIGURE 5.5 DIHYBRID CROSS

This dihybrid cross is heterozygous-heterozygous.



MAIN IDEA

Heredity patterns can be calculated with probability.

Probability is the likelihood that a particular event will happen. It predicts the average number of occurrences, not the exact number of occurrences.

$$\text{Probability} = \frac{\text{number of ways a specific event can occur}}{\text{number of total possible outcomes}}$$

Suppose you flip a coin. The number of total possible outcomes is two: heads up or tails up. The probability that it would land heads up is $1/2$, or one out of two. The probability that it would land tails up is also $1/2$.

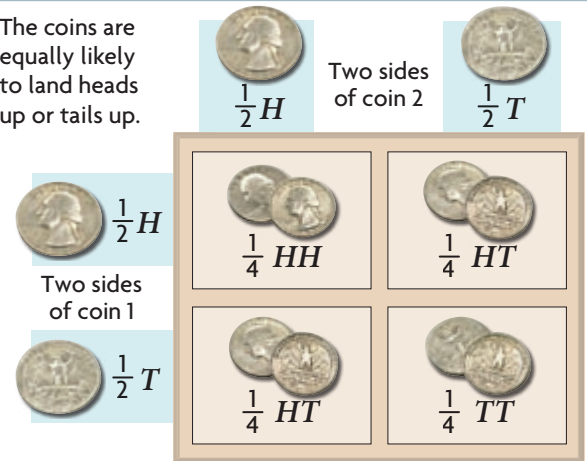
Next, suppose you flip two coins. How one coin lands does not affect how the other coin lands. To calculate the probability that two independent events will happen together, multiply the probability of each individual event. The probability that both coins will land heads up, for example, is $1/2 \times 1/2 = 1/4$.

These probabilities can be applied to meiosis. Suppose a germ cell undergoes meiosis in a plant that is heterozygous for purple flowers. The number of total possible outcomes is two because a gamete could get a dominant or a recessive allele. The probability that a gamete will get a dominant allele is $1/2$. The probability that it will get a recessive allele is also $1/2$.

If two plants that are heterozygous for purple flowers fertilize each other, the probability that both egg and sperm have a dominant allele is $1/2 \times 1/2 = 1/4$. So, too, the probability that both have a recessive allele is $1/4$. There is also a $1/4$ chance that a sperm cell with a dominant allele will fertilize an egg with a recessive allele, or that a sperm cell with a recessive allele will fertilize an egg with a dominant allele. These last two combinations are basically the same. In either case, the resulting plant will be heterozygous. Thus, the probability that a pea plant will be heterozygous for this trait is the sum of the probabilities: $1/4 + 1/4 = 1/2$.

FIGURE 5.6 PROBABILITY AND HEREDITY

The coins are equally likely to land heads up or tails up.



Apply Explain how Mendel's laws relate to probability.

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6.5 Formative Assessment

REVIEWING **MAIN IDEAS**

1. What do the grid boxes in a **Punnett square** represent?
2. Why does the expected genotypic ratio often differ from the expected phenotypic ratio resulting from a **monohybrid cross**?
3. How did Mendel's **dihybrid crosses** help him develop his second law?

CRITICAL THINKING

4. **Calculate** What would be the phenotypic ratios of the offspring resulting from the following cross: $YYRr \times YyRr$?
5. **Predict** If you are working with two tall pea plants and know that one is Tt , how could you determine the genotype of the other plant?



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PREMIUM CONTENT

CONNECT TO

ADAPTATION

6. You have seen that one-quarter of offspring resulting from two heterozygous parents are homozygous recessive. Yet for some genes, the recessive allele is more common in the population. Explain why this might be.