Part 2: Traits

Tyler has free earlobes like his father. His mother has attached earlobes. Why does Tyler have earlobes like his father? In this section you will learn about traits and how they are passed on to offspring. Look at your earlobes. Are they free or attached? (Figure 5). The type of earlobes you have is a trait that you inherited from your parents. A **trait** is a characteristic that an organism can pass on to its offspring.

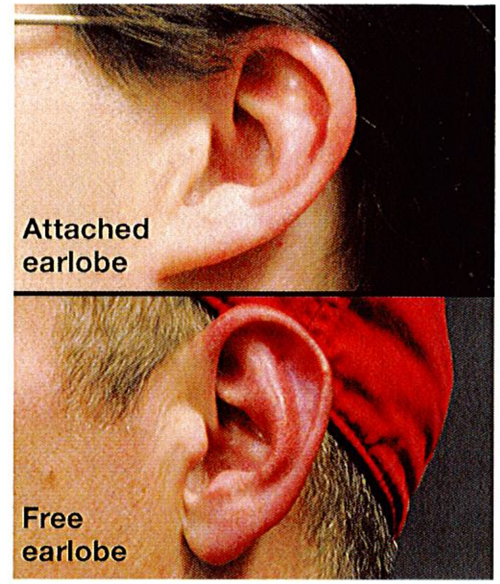


Figure 5: *The type of earlobes you have is a trait you inherited from your parents.*

Studying traits

Breeds and traits

Did you know there are over 150 dog breeds, but they are all the same species (*Canis familiaris*)? A pug looks completely different than a black lab, yet they both came from the same ancestors. For thousands of years, dog breeders have selected certain traits to produce dog breeds for different purposes. People knew how to breed in order to obtain certain traits long before scientists knew about DNA, chromosomes, or meiosis.

Genetics is the study of heredity

An organism's **heredity** is the set of traits it receives from its parents. **Genetics** is the study of heredity. Ancient dog breeders thought that the traits inherited by a dog were a blend of those from the mother and father. For example, a large dog crossed with a small dog in many cases would produce a medium-sized dog—a blend of both parents. It turns out that heredity is not that simple. A monk named Gregor Mendel was one of the first to find that out.

VOCABULARY

trait - a characteristic that an organism can pass on to its offspring.

heredity - a set of traits an organism receives from its parents.

genetics - the study of heredity.

The priest and the pea

Who was Gregor Mendel?

Gregor Mendel (1822 to 1884) was an Austrian monk. He is often called the "father of genetics." Through many years of experiments in breeding pea plants, Mendel arrived at some important conclusions about inheritance. However, nobody in his lifetime (including Mendel) realized the importance of his work. It was ignored by scientists until the early 1900s. Eventually Mendel's ideas led to the science of genetics.

Gregor Mendel

Disappearing traits

Mendel worked in a garden at the monastery where he lived. Through his work, he became interested in the traits of plants and how those traits were passed on to offspring. For example, he noticed that a trait that appeared in the parent generation of plants did not show up in their offspring (the first generation), but in the second generation, the trait showed up again (Figure 6)! Mendel wanted to find out why. So, he decided to study inheritance in peas. Peas were a good choice because they grow quickly and are easy to breed.

Peas and pollination

Peas are flowering plants. They have male and female parts on the same plant. Flowering plants reproduce by *pollination*. During pollination, pollen containing sperm from the male part of the plant is carried to the female part of the plant called the *ovule*. Fertilization occurs when a sperm from the pollen travels to an egg in the ovule. In a pea plant, pollen can fertilize eggs on the same plant (self-pollination). Or, the pollen can be carried by the wind or an animal to another plant. Figure 7 shows how pollination can occur.

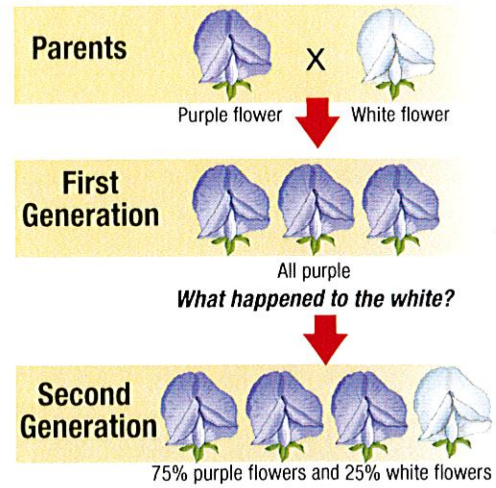


Figure 6: *Why do traits disappear and then reappear?*

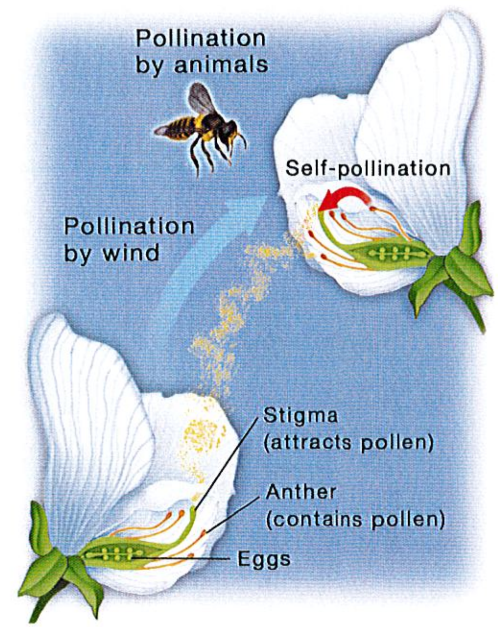


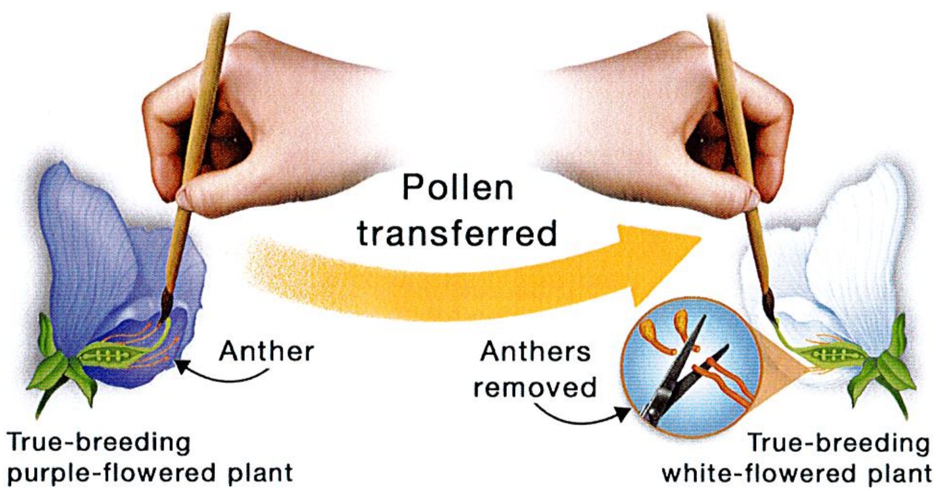
Figure 7: *Flowering plants reproduce by pollination.*

Mendel's experiment

Pea plant traits Mendel studied pea plants and identified several traits that had only two forms. For example, he observed that peas produced plants with either purple flowers or white flowers. Figure 8 shows four of the traits Mendel studied and their two forms.

True-breeding plants For his experiments, Mendel was careful to start out with true-breeding plants. When a **true-breeding plant** self-pollinates, it will always produce offspring with the same form of the trait as the parent plant. For example, a true-breeding plant with purple flowers will only produce plants with purple flowers.

Mendel's procedure for his experiments Mendel wanted to find out what would happen if he crossed two plants with different forms of a trait. He used a method called cross-pollination. In **cross-pollination**, the parts that contain pollen (anthers) are removed from one plant so it cannot self-pollinate. Next, the pollen from the other plant is used to fertilize the plant without pollen. The example below shows how Mendel crossed a purple-flowered plant with a white-flowered plant.



Four Pea Traits

TRAIT	FORM 1	FORM 2
Flower color	Purple	White
Seed shape	Smooth	Wrinkled
Seed color	Yellow	Green
Pod color	Green	Yellow

Figure 8: *Four of the traits Mendel studied in pea plants.*

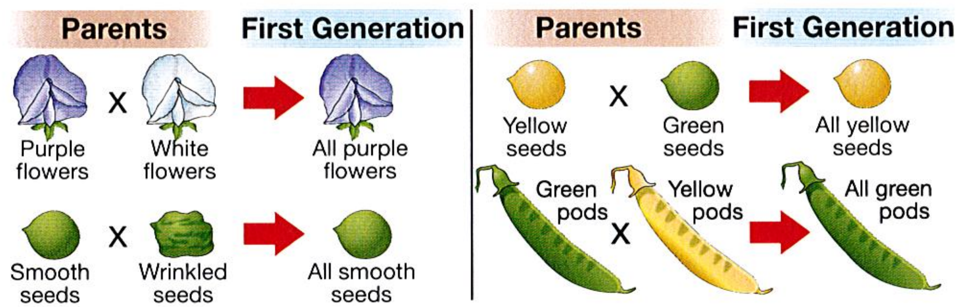
ă VOCABULARY

true-breeding plant - a plant that will always produce offspring with the same form of a trait when it self-pollinates.

cross-pollination - when the pollen from one plant is used to fertilize another plant.

The first generation

When Mendel crossed true-breeding, purple-flowered plants with true-breeding, white-flowered plants, the first generation produced all purple-flowered plants. Mendel got similar results for the other traits he studied. In each case, one form of the trait always showed up in the first generation and the other form of the trait always seemed to disappear.



The second generation

Next, Mendel allowed the first generation of plants to self-pollinate. When the purple-flowered plants of the first generation self-pollinated, white flowers showed up again in the second generation! Figure 9 shows Mendel's crosses with peas for the flower-color trait.

Calculating ratios

Mendel counted the plants in the second generation. He found 705 plants with purple flowers and 224 plants with white flowers. He calculated the ratio of purple-flowered plants to white-flowered plants. A *ratio* is a way to compare two numbers. Here's how to calculate the ratio of purple flowers to white flowers:

ratio symbol

1. Write as a fraction

3. Write as a ratio, rounded to the nearest whole number

$$705 \text{ purple} : 224 \text{ white} = \frac{705}{224} = \frac{(705 \div 224)}{(224 \div 224)} = \frac{3.15}{1} = 3{:}1$$

2. Divide top and bottom by the smallest number

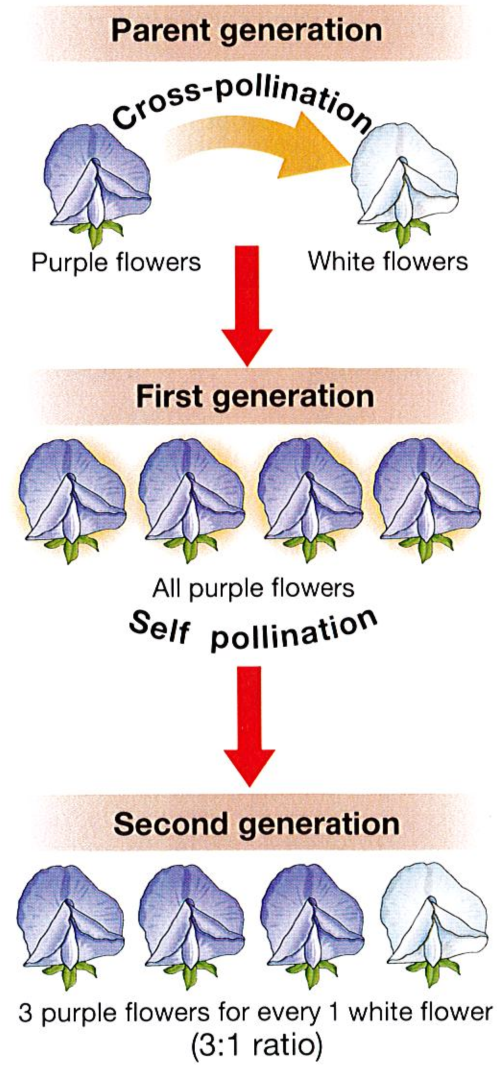


Figure 9: *Mendel's experiment.*

Mendel's conclusions

Second generation results Mendel got similar results for the second generation of all the traits he studied. The data from four of the traits he studied is shown in Table 1.1. For practice, calculate the ratio for the last three traits.

Table 1.1: The second generation from Mendel's peas

Trait	Form 1	Form 2	Ratio
Flower color	purple 705	white 224	3:1
Seed shape	round 5,474	wrinkled 1,850	?
Seed color	yellow 6,002	green 2,001	?
Pod color	green 428	yellow 152	?

Genes From the results, Mendel proved that all traits do not blend. For instance, purple flowers mixed with white flowers did not produce pink flowers. Mendel concluded that traits like flower color must be determined by individual *units*. Today, we call those units genes. A **gene** is a unit that determines traits.

Dominant and recessive alleles Mendel concluded that for each trait he studied, a pea plant must contain *two forms* of the same gene. Different forms of the same gene are called **alleles**. The **dominant allele** is the form of a gene that, when present, covers up the appearance of the recessive allele. The **recessive allele** is the form of a gene that is hidden when the dominant allele is present. The gene for flower color in peas has a dominant allele that causes purple flowers and a recessive allele that causes white flowers (Figure 10).

Alleles are different forms of the same gene. Organisms have at least two alleles for each gene—one from each parent.

VOCABULARY

gene - a unit that determines traits.

alleles - different forms of a gene.

dominant allele - the form of a gene that, when present, covers up the appearance of the recessive allele.

recessive allele - the form of a gene that is hidden when the dominant allele is present.

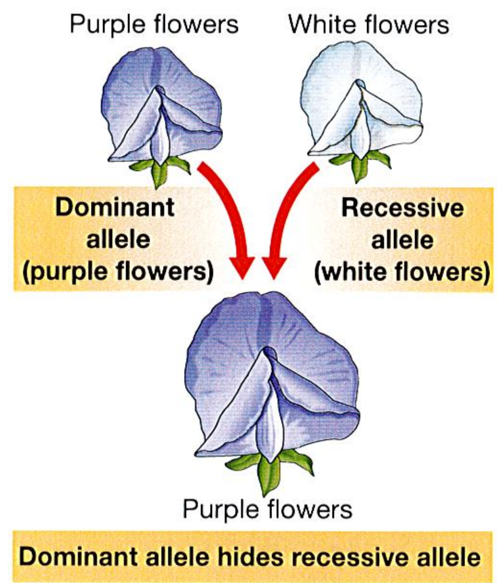


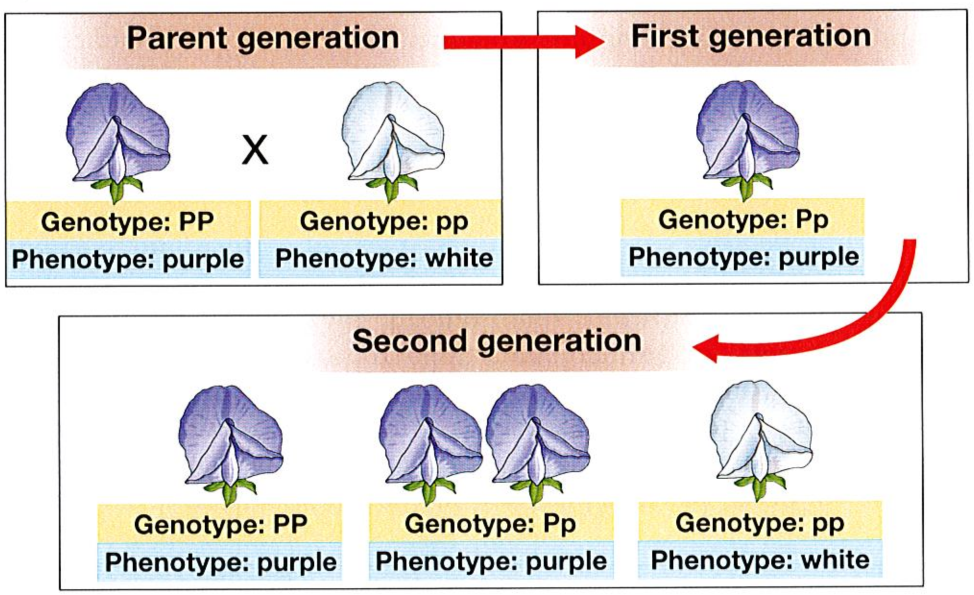
Figure 10: *Flower color in peas is determined by two alleles of the gene—one from each parent.*

Phenotype and genotype

An organism's **phenotype** is the form of a trait that it displays. For flower color, a pea plant can display a phenotype of purple or white flowers. An organism's **genotype** is the alleles of a gene it contains. Based on his data, Mendel concluded that a phenotype can be determined by more than one genotype.

Symbols for genes

Mendel used upper and lower case letters to symbolize the alleles of a gene. For flower color, he used upper case ***P*** for purple (the dominant allele) and lower case ***p*** for white (the recessive allele). A pea plant with purple flowers could have a genotype of either ***PP*** or ***Pp***. A pea plant with white flowers could only have a genotype of ***pp***. As long as at least one dominant allele is present, the plant will always have a phenotype of purple flowers. Figure 11 shows the genotypes and phenotypes of four pea plant traits. The graphic below shows the alleles present in each generation of pea plants from Mendel's experiment.



VOCABULARY

phenotype - the form of a trait that an organism displays.

genotype - the alleles of a gene an organism contains.

Flower color — Purple (P), White (p)

Genotype	Phenotype
PP	Purple
Pp	Purple
pp	White

Seed shape — Round (R), Wrinkled (r)

Genotype	Phenotype
RR	Round
Rr	Round
rr	Wrinkled

Seed color — Yellow (Y), Green (y)

Genotype	Phenotype
YY	Yellow
Yy	Yellow
yy	Green

Pod color — Green (G), Yellow (g)

Genotype	Phenotype
GG	Green
Gg	Green
gg	Yellow

Figure 11: *The genotypes and phenotypes of four of the traits Mendel studied in pea plants.*

Part 3: Predicting Heredity

When Mendel published his work in the 1800s, he did not use the word "gene" to describe his units of heredity. He also wasn't sure where his units might be found or how to identify them. His work went unnoticed for almost thirty years. In 1902, American scientist Walter Sutton (1877 to 1916) examined the nuclei of grasshopper cells under a microscope. He observed that chromosomes occurred in homologous pairs that separated during meiosis. A year later, Sutton found that chromosomes contained *genes*. He had discovered Mendel's units of heredity! In this section you will learn how Mendel's work is used to predict the heredity of offspring.

How traits are passed on to offspring

Genes and alleles Mendel developed the basic laws of how traits are passed on to offspring (Figure 12). He did not know about genes, chromosomes, DNA, or meiosis. The laws stated below combine the work of Mendel and Sutton.

1. **Individual units called genes determine an organism's traits.**
2. **A gene is a segment of DNA, located on the chromosomes, that carries hereditary instructions from parent to offspring.**
3. **For each gene, an organism typically receives one allele from each parent.**
4. **If an organism inherits different alleles for a trait, one allele may be dominant over the other.**
5. **The alleles of a gene separate from each other when gametes are formed during meiosis.**

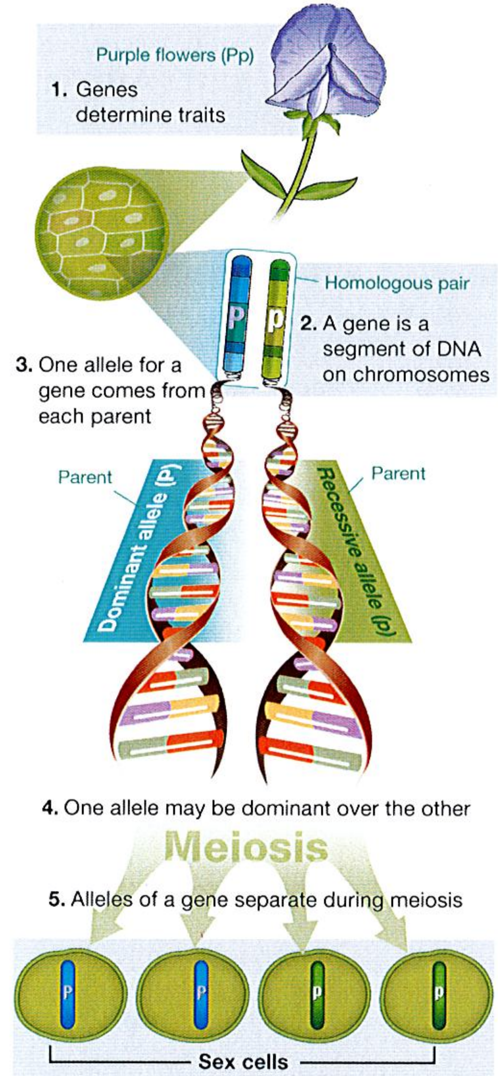


Figure 12: *The principles of how traits are passed on to offspring.*

Alleles and meiosis

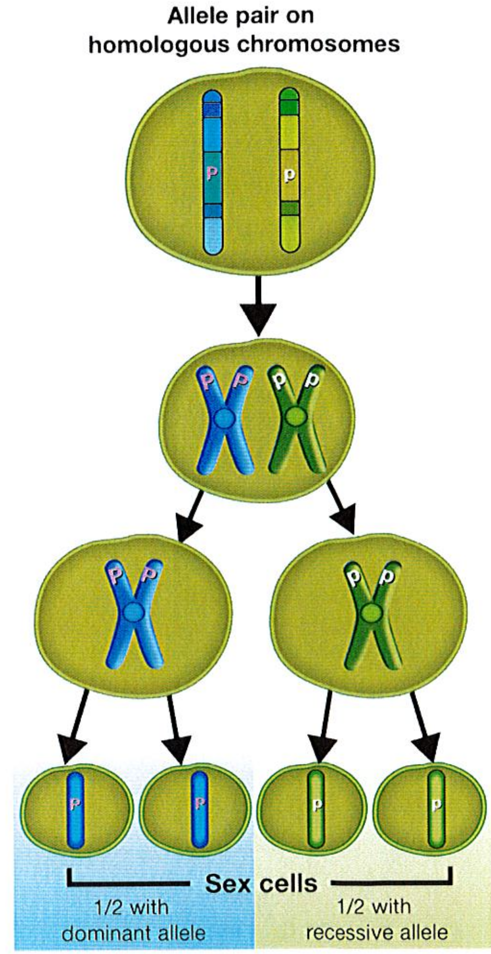


Figure 13: *Alleles of a gene are found in corresponding locations on homologous pairs of chromosomes.*

Alleles of a gene separate during meiosis

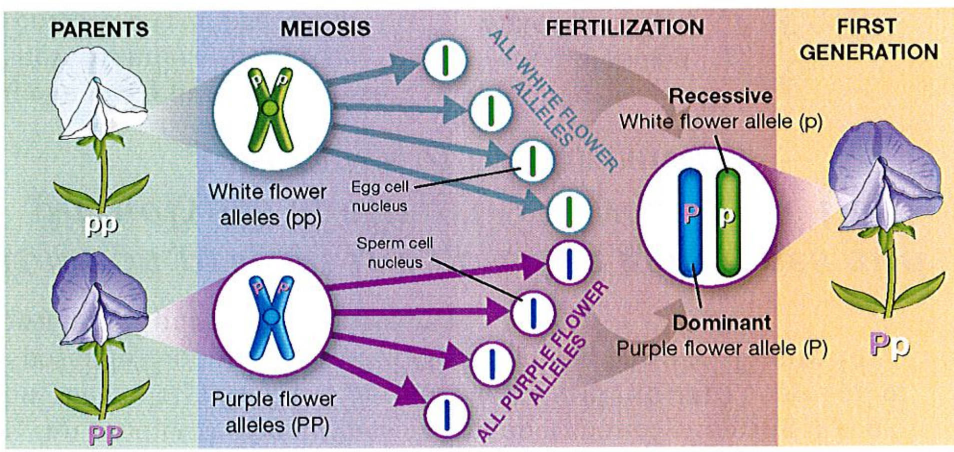
In the last chapter, you read that homologous pairs of chromosomes separate during meiosis. Since alleles of a gene are found in corresponding locations on homologous pairs of chromosomes, they also separate during meiosis.

How do alleles separate?

To illustrate how alleles separate, let's follow the alleles for the flower color trait in a pea plant with the genotype ***Pp***. The plant in our example has a dominant allele (***P***) and a recessive allele (***p***). What is the phenotype of the plant? You are correct if you said purple! Figure 13 shows what happens to the alleles during meiosis. To keep it simple, only one pair of chromosomes is shown. A real pea plant has 14 chromosomes (7 pairs).

Fertilization

When fertilization occurs, offspring inherit one homologous chromosome in a pair from each parent. As a result, one allele for a gene also comes from each parent. When Mendel crossed pure-breeding, purple-flowered plants with pure-breeding, white-flowered plants, the first generation offspring were purple with the genotype ***Pp***. The diagram below traces the alleles from parent to offspring.

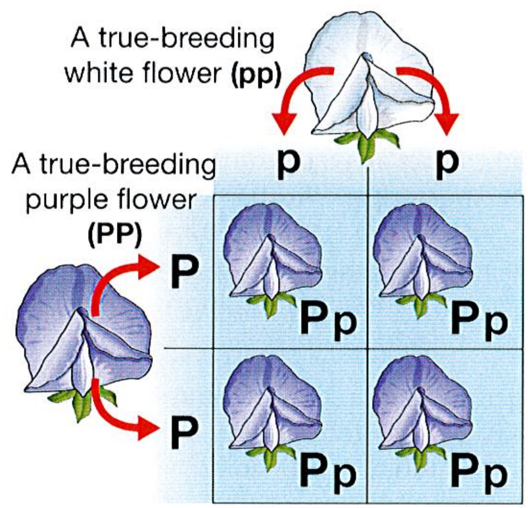


Predicting genotype and phenotype

Punnett squares You can predict the genotypes and phenotypes of offspring if you know the genotypes of the parents. A **punnett square** shows all of the possible combinations of alleles from the parents. Figure 14 shows how a punnett square is made.

You can predict the possible genotypes and phenotypes of offspring if you know the genotypes of the parents.

A punnett square of Mendel's first cross You can use a punnett square to show Mendel's first cross. He crossed a true-breeding, purple-flowered plant with a true-breeding, white-flowered plant. Since the purple-flowered plant is true-breeding, it has two dominant alleles. The genotype of the purple-flowered plant is ***PP***. Since white flowers are recessive, the only possible genotype for a white-flowered plant is ***pp***.



Analyzing the punnett square As you can see, all of the offspring in Mendel's first cross had a genotype of ***Pp***. That's why all of the plants in the first generation had purple flowers. Using a punnett square, you can predict the possible genotypes and phenotypes of the offspring. In the example above, the only possible genotype is ***Pp*** and the only possible phenotype is purple flowers.

VOCABULARY

punnett square - shows all of the possible combinations of alleles from the parents.

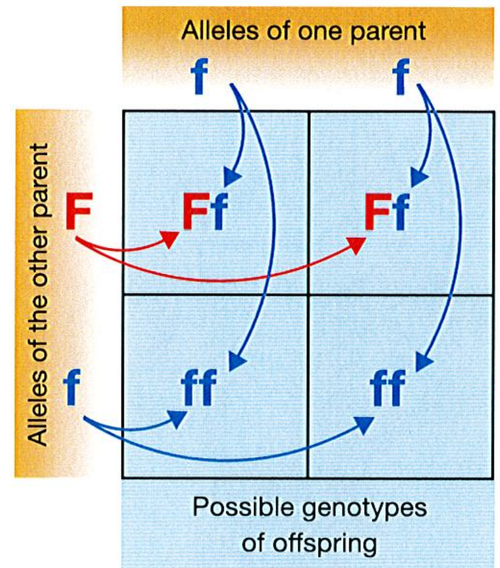


Figure 14: *The parts of a punnett square.*

SOLVE IT!

In the punnett square shown in Figure 14, F = free earlobes and f = attached earlobes. What is the genotype and phenotype of each parent? What are the possible genotypes and phenotypes of their children?

Punnett squares and probability

A punnett square of Mendel's second cross

When Mendel let the ***Pp*** plants self-pollinate, white flowers showed up in the second generation. Figure 15 shows a punnett square of the cross. Recall that when Mendel counted the plants, he found a 3:1 ratio of purple to white flowers. There are three possible genotypes from the cross. Of the three, ***PP***, and ***Pp*** are purple because they have the dominant allele. Only one of the three (***pp***) is white. From looking at Figure 15, can you see why there is a 3:1 ratio of purple-flowered to white-flowered plants?

Probability

When you flip a coin, there is a 50 percent chance you'll get heads and a 50 percent chance you'll get tails. The way the coin lands is completely random. Like flipping a coin, the chance of inheriting a certain genotype and phenotype is random. **Probability** is the mathematical chance that an event will occur.

Punnett squares and probability

Probability can be expressed as a fraction or a percentage. A punnett square represents all of the *possible* genotypes of offspring. In Figure 15, 1 out of the 4 squares is ***pp***. The probability of offspring having ***pp*** is therefore 1/4. To convert this to a percentage, take the numerator of the fraction divided by the denominator and multiply by 100:

$$\frac{1}{4} \times 100 = 25\%$$

There is a 25 percent chance of offspring having the ***pp*** genotype. What is the probability of offspring having purple flowers? ***PP***, and ***Pp*** have purple flowers. That's 3 out of the 4 squares. The probability is:

$$\frac{3}{4} \times 100 = 75\%$$

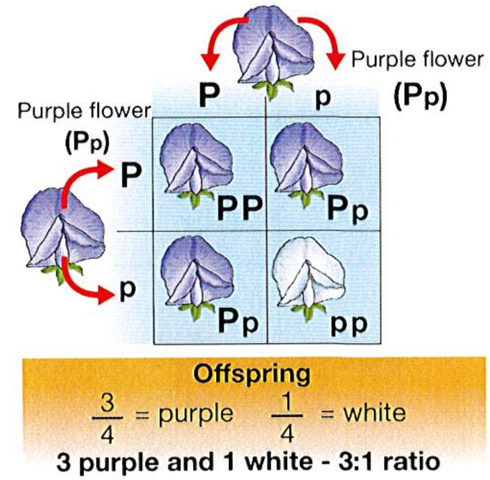


Figure 15: *A cross between pea plants of the first generation. The plants have a dominant and recessive allele. Can you see why white flowers showed up in the second generation?*

VOCABULARY

probability - the mathematical chance that an event will occur.

Part 4: Other Patterns of Inheritance

Perhaps it was luck for Mendel (and science) that he happened to use pea plants to discover the principles of heredity. Peas happen to have a number of traits that are determined by just two alleles. Also, for the traits he studied, one allele happened to be dominant and the other recessive. Mendel discovered an important pattern of inheritance and his laws are the foundation of genetics. Since plant and animals have *thousands* of genes, some have patterns of inheritance that are different from the ones Mendel discovered. In this section, you will learn about some of those patterns.

Male or female?

Sex chromosomes Mendel worked with peas that had female and male parts on the same plant. Many organisms, like humans, have separate female and male individuals. In humans, sex is determined by the last pair of chromosomes, called sex chromosomes (Figure 16). **Sex chromosomes** carry genes that determine whether an individual is female or male.

Male and female genotypes The female chromosome is symbolized with an *X* and the male with a *Y*. A female has two *X* chromosomes in her body cells. Her genotype is *XX*. A male has an *X* and a *Y* chromosome in his body cells. His genotype is *XY*. During meiosis, the sex chromosome pairs separate. Females produce eggs with an *X* chromosome. Males produce sperm with an *X* or a *Y* chromosome. Figure 17 shows a punnett square that crosses a male and a female. What are the chances of having a boy or a girl?

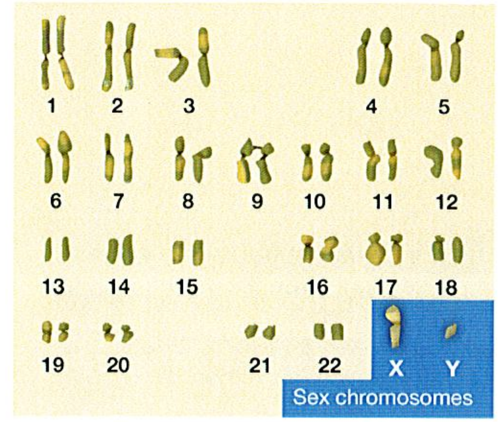


Figure 16: *In humans, sex is determined by the last pair of chromosomes. What is the sex of this person?*

	Male X	Male Y
Female X	XX	XY
Female X	XX	XY

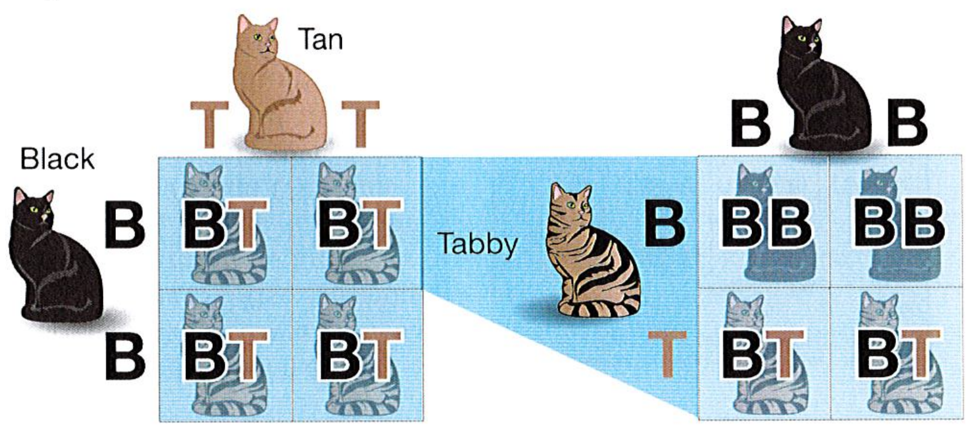
Figure 17: *A cross between a male and a female.*

Incomplete dominance and codominance

Pink flowers from red and white! Sometimes one allele isn't completely dominant over the other. If you cross a true-breeding, red-flowered snapdragon (***RR***) with a true-breeding, white-flowered snapdragon (***WW***), you may expect the first generation to have all red flowers. In snapdragons, this does not happen. The first generation has *pink* flowers (Figure 18)! When you cross two pink-flowered snapdragons (***RW***), the second generation of plants will have 25% red flowers, 50% pink flowers, and 25% white flowers.

Incomplete dominance Flower color in snapdragons is an example of incomplete dominance. In **incomplete dominance**, the phenotypes of the two alleles blend—just like mixing paints. Notice that in Figure 18, we use ***R*** for the red allele and ***W*** for white allele instead of upper and lower cases of the same letter.

Codominance In **codominance**, an organism that has both alleles of a gene displays *both* phenotypes at the same time. For example, a cross between a black cat (***BB***) and a tan cat (***TT***) results in a tabby cat (black and tan mixed together). Suppose a tabby cat (***BT***) crossed with a black cat (***BB***). What is the probability that one of their kittens would have tabby fur?



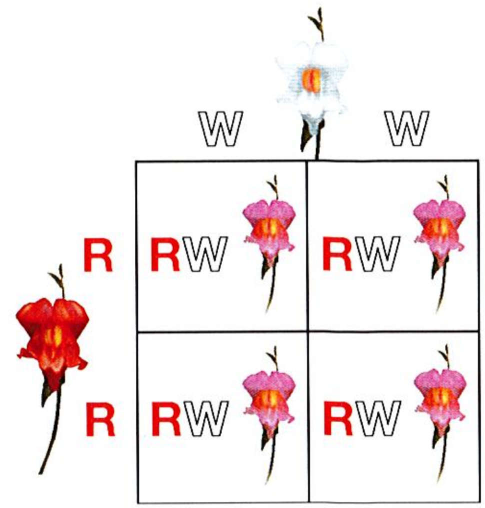


Figure 18: *A cross between red-flowered snapdragons and white-flowered snapdragons produces pink-flowered snapdragons. The second generation has red, pink, and white flowers.*

VOCABULARY

incomplete dominance - when the phenotype of the two alleles blend.

codominance - when an organism that has both alleles of a gene displays both phenotypes at the same time.

Other patterns of inheritance and environmental factors

Multiple alleles So far you have learned about genes that have just two alleles. *Multiple alleles* are also common in organisms. In humans for example, *three* alleles determine blood type (***A***, ***B***, and ***O***). Each person can have only two of the alleles at one time, but there are three alleles in the human population. If a person inherits a B allele from one parent and a O allele from the other parent, she will have type B blood. The diagram (right) shows the possible genotypes and phenotypes for human blood type.

Parent Alleles ▶ ▼	A	B	O
A	AA (Type A)	AB (Type AB)	AO (Type A)
B	AB (Type AB)	BB (Type B)	BO (Type B)
O	AO (Type A)	BO (Type B)	OO (Type O)

Polygenic traits Inherited traits that are determined by more than one gene are called **polygenic traits**. Have you ever seen parakeets in a pet store? Feather color in parakeets is determined by two genes. One gene controls yellow color and the other controls blue color. Figure 19 shows the possible genotypes and phenotypes. In humans, eye color and skin color are polygenic traits. The range in skin colors of humans is determined by no less than four genes!

Environmental factors Genes aren't the only influence on the traits of an organism. Environmental factors may also influence traits. For instance, in some turtle species, sex is determined by temperature. During the development of the embryo, higher temperature favors the production of males. Human height is determined by genes. But if a person does not get the proper nutrients, he or she may not reach his or her potential height.

ă VOCABULARY

polygenic traits - traits that are determined by more than one gene.

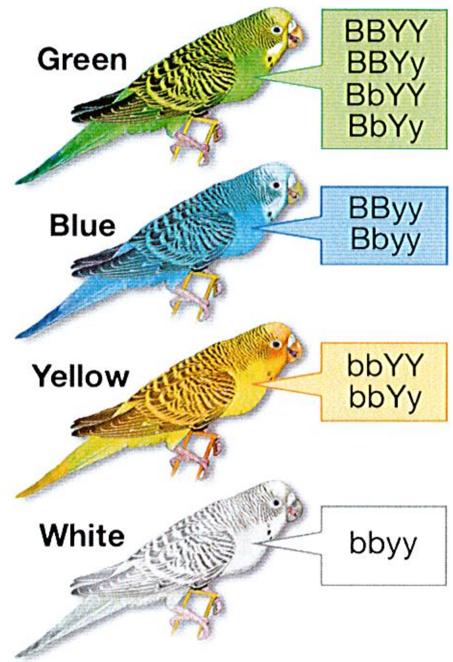


Figure 19: *Feather color in parakeets is determined by two genes.*