Chapter 6

Inheritance

6.6 Beyond Mendel

Mendel's work provided the vital first steps in our understanding of inheritance. But inheritance can also be more complicated than what Mendel described. Let's consider some additional wrinkles.

Incomplete Dominance

In **incomplete dominance**, there are two alleles for a trait, and neither is dominant. The heterozygote has an intermediate trait. For example, when you breed a red snapdragon with a white snapdragon, you get pink snapdragons (Figure 6.14).

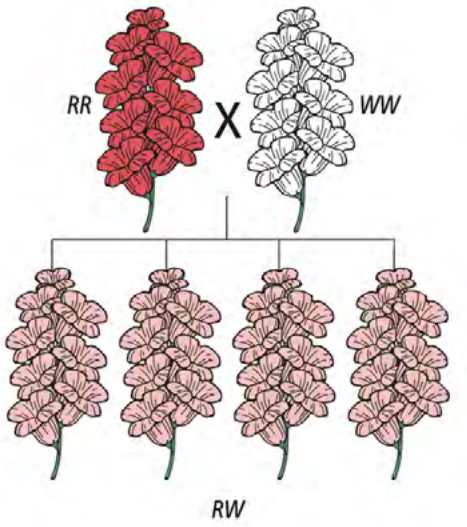


FIGURE 6.14

Flower color in snapdragons shows incomplete dominance. When a snapdragon with red flowers (RR) is bred with a snapdragon with white flowers (WW), the offspring (RW) have pink flowers.

Codominance

In **codominance**, a heterozygote with two different alleles expresses the traits of *both* alleles. An example can be found in human blood type. Your blood type describes molecules on the surface of your red blood cells. Knowing your blood type can be a matter of life and death. If you ever receive blood cells with a surface molecule you don't normally have, your body attacks them. This makes the blood cells clump together, which can be fatal.

Depending on your blood type, you can have the A molecule (blood type A), the B molecule (blood type B), neither (blood type O), or both (blood type AB). There are three blood type alleles: *A, B*, and *O*. A person with genotype *AA* or *AO* has A molecules (blood type A). A person with genotype *BB* or *BO* has B molecules (blood type B). A person with genotype *OO* has neither molecule (blood type O). A person with genotype *AB* has both A and B molecules (blood type AB)—both the *A* trait and the *B* trait are expressed. The *A* and *B* alleles are codominant (Figure 6.15).

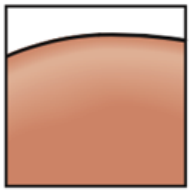
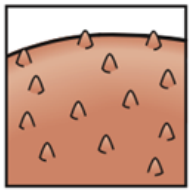
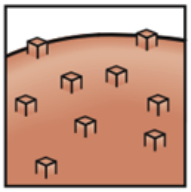
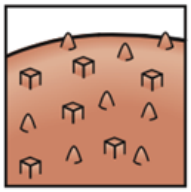
Blood type (Phenotype)	O	A	B	AB
				
Genotype	*OO*	*AA* or *AO*	*BB* or *BO*	*AB*

FIGURE 6.15

Human blood type offers an example of codominance. Blood type is determined by combinations of the A, B, and O alleles. A and B are both dominant to O, but A and B are codominant.

Polygenic Traits

Polygenic traits are determined by more than one gene. (*Poly* means "many," so *polygenic* refers to "many genes.") Human height and skin color are both polygenic. Polygenic traits show more of a continuum than traits determined by a single gene. To see why, consider human height.

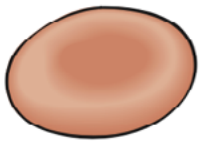
Suppose the three genes A, B, and C determine height. (More than three genes are actually involved.) Each gene has a tall allele and a short allele, which we will indicate with *T* and *S*. The shortest people have all short alleles—genotype $A_SA_SB_SB_SC_SC_S$. People with genotype $A_SA_SB_TB_SC_SC_S$ (five short alleles and one tall allele) are somewhat taller, those with four short alleles and two tall alleles are even taller, and so on. In this way, multiple genes produce a gradation of heights (Figure 6.16).

FIGURE 6.16

Human height is a polygenic trait. Taller people have more tall alleles. (Height is also affected by nongenetic factors such as diet and nutrition.)

Pleiotropy

In **pleiotropy**, a single gene affects more than one trait. The disease sickle cell anemia provides an example of pleiotropy in humans. The sickle-cell allele for hemoglobin makes red blood cells turn sickle-shaped under certain conditions, causing tissue damage and pain (Figure 6.17). Homozygotes (people who have two sickle-cell alleles) are severely affected. Heterozygotes (people who have one sickle-cell allele and one normal allele) have only mild symptoms. Given the sickle-cell allele's harmful effects, scientists were puzzled by how common it is, especially among people of African descent. Why hadn't evolution through natural selection caused the sickle-cell allele to disappear from human populations?



Normal red blood cell

Sickled red blood cell

Pleiotropy provides the answer. It turns out that the sickle-cell allele also protects people from malaria. This is an example of pleiotropy because the sickle-cell allele affects more than one trait—it affects the shape of red blood cells *and* resistance to malaria. The fact that the sickle-cell allele protects against malaria—along with the allele's mild symptoms in heterozygotes—explains why the allele is common in populations where malaria has been a danger in the past.

FIGURE 6.17

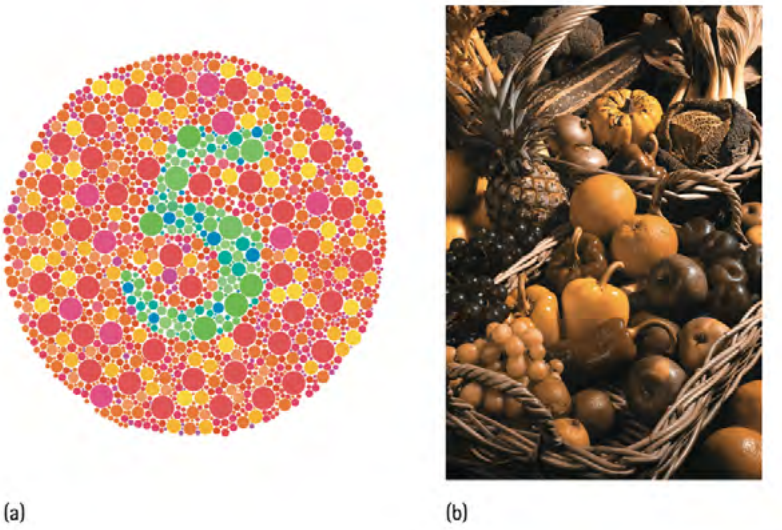
The sickle-cell allele offers an example of pleiotropy in humans. The allele can cause normally round red blood cells to assume a sickle shape, resulting in pain and tissue damage. However, the allele also offers protection from malaria.

Linked Genes

Linked genes are frequently inherited together, in apparent contradiction to Mendel's principle of independent assortment. How can genes be linked? Independent assortment occurs when alleles found on *different* chromosomes separate independently at meiosis. But, if the alleles for two genes are on the *same* chromosome, they are often inherited together—though not quite all the time, because sometimes crossing over shuffles them up. In fact, the closer two alleles are to each other on a chromosome, the more likely they are to be inherited together. (The genes for Mendel's pea traits happened to be on different chromosomes—that's why he concluded that genes sort independently.) Body color and wing size in fruit flies are linked genes.

Sex-Linked Traits

Sex-linked traits are determined by genes found on the X chromosome. Because males have only one X chromosome, they have only one allele for these traits. This means that males need only one recessive allele to express a recessive sex-linked trait, whereas females need two recessive alleles. Because of this, recessive sex-linked traits are seen more often in males than in females. In humans, two recessive sex-linked traits are red-green color-blindness (Figure 6.18) and the blood disease hemophilia. Both conditions affect far more males than females.



(a) (b)

FIGURE 6.18

Red-green color-blindness is a sex-linked trait that affects many more males than females. (a) This image is used to test for red-green color-blindness. Do you see the number? (b) This photo shows how a plate of fruits and vegetables would appear to a person with red-green color-blindness.

Horizontal Gene Transfer

We inherit traits from our parents. This much is clear. But because nature is rather creative, it's also quite possible to receive genes from elsewhere, including even another species. For example, microorganisms such as bacteria sometimes receive genes through the action of viruses that infect them. This type of transmission is called *horizontal gene transfer*. (The term "horizontal" distinguishes this from the "vertical" transmission from parents to offspring we have been studying up to now.) In many cases, horizontal gene transfer occurs between species, such as when a virus transmits a gene to a bacterium. Horizontal gene transfer in bacteria explains, in part, how bacteria can quickly evolve to become resistant to our antibiotics. As we will explore in the next chapter, viral DNA found in bacteria has also led to a revolutionary gene editing tool called CRISPR-Cas9.

Other living things are likewise impacted by horizontal gene transfer. In fact, the mitochondria found in all eukaryotic cells (remember that mitochondria are organelles that break down organic molecules and generate energy in the form of ATP) are likely the remnants of an ancient organism that infected our cells only to become permanently incorporated. Furthermore, it's estimated that about 8 percent of the human genome arrived not through traditional inheritance but through viral infection, that is, horizontal gene transfer. The main point is that nature is creative and there is still much we have to learn when it comes to genetic inheritance.

READING CHECK

Your blood type is O, your mother's blood type is A, and your father's blood type is B. What is your genotype? What about your mother's and your father's? Explain your reasoning.

CHECK YOUR ANSWERS

Because your blood type is O, your genotype must be *OO*. Your mother's blood type is A, so she must have the genotype *AO*. (She must have an *O* allele because she passed one to you.) Similarly, your father must be *BO*.