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LESSON 1

Genes and Heredity

Major Understandings 4LE2.1a–c; 4LE2.2a–c

All organisms have distinct traits. A **trait** is a physical or behavioral characteristic. Inherited traits are passed to offspring by their parents. The processes of inheritance involve genetic structures—chromosomes, DNA, and genes. If you understand how genes determine traits, you can predict the traits of offspring.

A **trait** is a characteristic of an organism's appearance or behavior.

Chromosomes, Genes, and DNA

All organisms have a chemical code called **DNA** inside their cells. DNA is a molecule that stores information about inherited traits. The DNA in cells is arranged in **chromosomes.** Chromosomes are thread-like structures that hold all of the hereditary information of an organism. Each human body cell contains 46 chromosomes.

Regions of DNA called **genes** control, or code for, particular traits. Certain genes may determine a person's eye color. Other genes determine the shape of a person's face. Some genes code for a single trait. Some genes affect multiple traits. And some traits are determined by more than one gene.

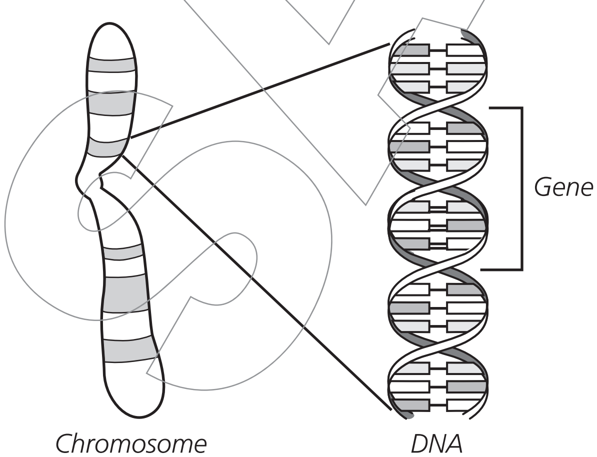
Organisms inherit their genes from their parents. Humans and many other organisms that reproduce sexually have two copies of every gene in their bodies. An individual receives one copy of each gene from its mother and one copy from its father. In some cases, the two copies of a gene are the same. In other cases, the two copies of each gene are slightly different.

Each human body cell contains all the genes needed to produce a human being. The illustration below shows the relationship between chromosomes, DNA, and genes.

DNA is a chemical molecule that carries a genetic code.

A **chromosome** is a thread-like structure made up of DNA.

A **gene** is a segment of DNA that carries a single unit of genetic information.



Different combinations of genes can produce different traits. For example, several genes determine the color of a person's eyes. Some combinations of these genes produce hazel eyes. Other combinations produce green eyes. Still other combinations produce brown eyes or blue eyes.

What fraction of a boy's genes come from his mother, and what fraction come from his father?

A $\frac{1}{4}$ from his mother, $\frac{3}{4}$ from his father

B $\frac{1}{2}$ from his mother, $\frac{1}{2}$ from his father

C $\frac{3}{4}$ from his mother, $\frac{1}{4}$ from his father

D all from his father

Each person receives one copy of each gene from his or her mother and one copy from his or her father. Therefore, half of every person's genes come from the mother and half come from the father. The correct answer is B.

Genetics—The Study of Heredity

Heredity is the passing of traits from one generation to the next. **Genetics** is the study of the processes of heredity. The science of genetics began in the 1800s with the work of Austrian botanist Gregor Mendel. Mendel studied the inheritance of particular traits in pea plants. The principles he discovered apply to many other organisms and form the foundation of our modern understanding of genetics.

Mendel studied traits such as seed color in pea plants. Seed color is determined by a gene that has two forms. One form codes for yellow seeds. The other form codes for green seeds. Mendel mated, or crossed, different pea plants and observed their offspring. Each offspring inherited one gene for seed color from one parent and one gene for seed color from the other parent.

Mendel discovered that some genes in pea plants are **dominant genes.** Later, scientists discovered that dominant genes also exist in other organisms, including humans. Dominant genes are always expressed. That is, the organism that inherits the gene will show the trait it codes for. This means that an organism needs only one copy of the dominant gene to show the trait it codes for.

In pea plants, the gene for yellow seeds is dominant. If a pea plant inherits one or two genes for yellow seeds, it will have yellow seeds. Dominant genes are represented by italicized capital letters, such as *Y* (for yellow seeds).

Heredity refers to the passing of traits from parents to offspring.

Scientists who study **genetics** study how traits are passed from parents to offspring.

The trait of a **dominant gene** is always expressed.

In pea plants, the gene for green seeds is a **recessive gene.** The expression of a recessive gene is blocked by the presence of a dominant gene for the same trait. Therefore, an organism must inherit two copies of a recessive gene to express the trait it codes for. Recessive genes are represented by italicized lowercase letters, such as *y* (for green seeds). A pea plant must get the *y* gene for seed color from both parents to have green seeds.

The trait of a **recessive gene** is expressed only if no dominant gene for the trait is inherited.

There are four possible combinations of the genes for seed color in pea plants. These combinations are *YY*, *Yy*, *yY*, and *yy*. When the dominant *Y* gene is present, the plant has yellow seeds. This means that *YY*, *Yy*, and *yY* pea plants all have yellow seeds. When the *Y* gene is absent, the recessive green trait's expression is not blocked. Therefore, *yy* pea plants have green seeds. The table below summarizes this information.

PEA PLANT SEED COLORS

Gene Combination	Seed Color
YY	yellow
Yy or *yY*	yellow
yy	green

Not all traits have dominant and recessive genes. For example, the gene for flower color in carnations has two forms. A plant with two *R* genes has red flowers. A plant with two *W* genes has white flowers. A plant with one *R* gene and one *W* gene has pink flowers. Neither the *W* nor the *R* gene is dominant.

Punnett Squares and Predictions

Although most organisms have two full sets of genes, a parent will pass on only one set of genes to its offspring. Suppose a pea plant is *Yy* for seed color. It is mated to another pea plant that is also *Yy*. Each plant will pass on either the dominant *Y* gene or the recessive *y* gene to its offspring.

Each offspring will inherit either a *Y* gene or a *y* gene from each of its parents. Therefore, the offspring can have different combinations of genes for seed color. For example, one offspring might inherit a *Y* gene from one parent and a *y* gene from the other parent. It will be *Yy* for seed color. Another offspring might inherit a *y* gene from each parent, so it will be *yy* for seed color.

There is no way to predict exactly which genes an individual will inherit from its parents. Therefore, there is no way to predict the traits of an individual organism. However, scientists can use a model called a **Punnett square** to predict the probability that offspring will have certain traits.

A **Punnett square** is a model that shows the possible genetic makeup of offspring.

A Punnett square shows the combinations of genes that an offspring can inherit from its parents. In a Punnett square, the genes of the parents are written above and to the left side of a grid. The possible combinations of these genes are written in the four boxes of the grid, as shown below.

PUNNETT SQUARE OF *Yy* × *Yy*

	Y	*y*
Y	*YY*	*yY*
y	*Yy*	*yy*

The Punnett square above shows the possible gene combinations of offspring from two *Yy* pea plants. It shows that their offspring have a 1 in 4 chance of inheriting a *y* gene from both parents (*yy*). They have a 1 in 4 chance of inheriting a *Y* gene from both parents (*YY*). They have a 2 in 4 chance of inheriting a *y* gene from one parent and a *Y* gene from the other parent (*yY* or *Yy*). In other words, there is a 25% chance that any one offspring will be *yy*, a 25% chance that any one offspring will be *YY*, and a 50% chance that any one offspring will be *Yy* or *yY*.

You can use a Punnett square to predict how many offspring will have a certain trait. For example, the Punnett square above shows that 1 in 4, or 25%, of the offspring of this cross will have green seeds (*yy*). The other 75% of the offspring will have yellow seeds (*YY*, *Yy*, or *yY*). If the cross produced 100 offspring, about 25 would have green seeds and about 75 would have yellow seeds.

Scientists can also use Punnett squares to predict gene combinations in people. For example, in people, a dominant gene, *D*, codes for dimples and a recessive gene, *d*, codes for no dimples. The Punnett square below shows the probability of gene combinations in children from the mating of a *DD* parent with a *Dd* parent.

PUNNETT SQUARE OF *DD* × *Dd*

	D	*D*
D	*DD*	*DD*
d	*Dd*	*Dd*

In this case, there is a 50% probability that any one offspring will inherit a pair of *DD* genes. There is also a 50% probability that any one offspring will be *Dd*. You can also see that all of the possible offspring will have at least one *D* gene. Since this gene is dominant for dimples, all of the children will have dimples.

Remember that you cannot use a Punnett square to predict the genetic makeup of any individual offspring. Therefore, you cannot use a Punnett square to predict the exact number of offspring that will have a certain trait. For example, you could use a Punnett square to predict that about 75% of pea plant offspring will have yellow seeds. However, if you studied 100 offspring, there might actually be 78 with yellow seeds. Or, there might be only 72. The more offspring you study, the closer the percentages will get to those predicted by the Punnett square.

In pea plants, the gene for smooth seeds (*R*) is dominant, and the gene for wrinkled seeds (*r*) is recessive. If an *RR* plant is crossed with an *rr* plant, what percentage of the offspring will have wrinkled seeds?

A 0%

B 25%

C 75%

D 100%

First, construct a Punnett square for the cross. The Punnett square is shown below.

PUNNETT SQUARE OF *RR* × *rr*

	R	*R*
r	*Rr*	*Rr*
r	*Rr*	*Rr*

The Punnett square shows that each offspring will inherit one *R* gene from one parent and one *r* gene from the other parent. Therefore, all of the offspring will be *Rr* for seed shape. The *R* gene is dominant, so all of the offspring will have smooth seeds. None of the offspring—0%—will have wrinkled seeds, so the correct answer is A.

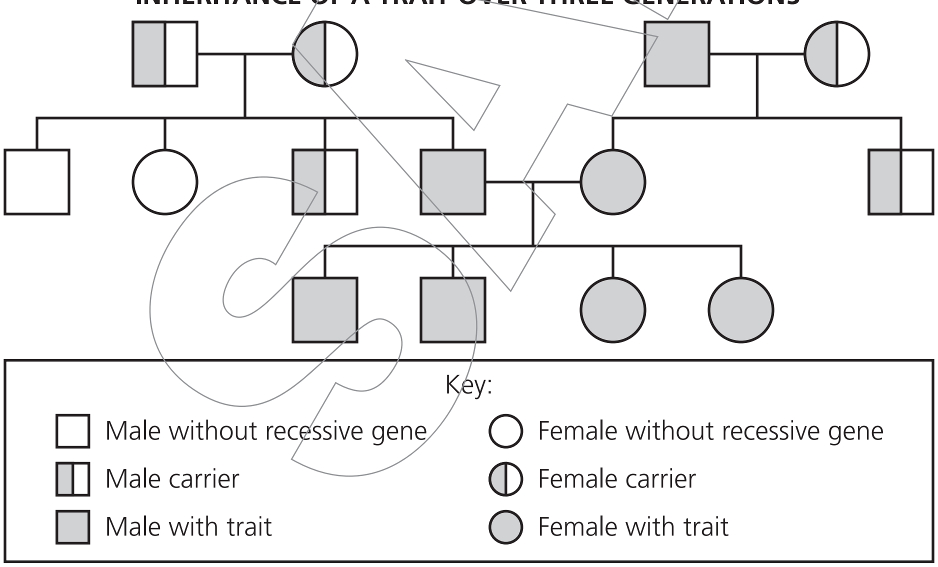
Pedigree Diagrams

Scientists use a model called a **pedigree diagram** to trace, analyze, and predict the inheritance of traits over a number of generations. In a pedigree diagram, squares and circles are used to represent individuals. Squares represent males. Circles represent females. Lines represent mating between individuals and show the offspring of individuals.

For example, study the pedigree diagram below. It shows the inheritance of a trait in three generations of a family.

A **pedigree diagram** is a model that shows the traits of parents and offspring over several generations.

INHERITANCE OF A TRAIT OVER THREE GENERATIONS



White circles or squares represent individuals without the recessive gene. Black circles or squares represent individuals with the trait. These individuals have two copies of the recessive gene. Circles or squares that are half-black and half-white represent carriers. A carrier is a person that has one dominant gene and one recessive gene for a trait. Carriers do not have the trait, but they can pass it along to their offspring.

The first generation is shown at the top. There are two couples in the first generation. The first couple was a male carrier and a female carrier. The second couple was a male with the trait and a female carrier. The first couple had four children: three males and one female. The second couple had two children: one male and one female. These six children make up the second generation. Two of them have the trait. Two are carriers. Two do not have the recessive gene.

One of the males with the trait mated with one of the females with the trait. They had four children: two males and two females. All four of them have the trait.

Assume that the dominant gene for the trait is *F* and the recessive gene is *f*. Identify which genes each individual in the pedigree chart has.

All of the individuals with the trait (black circles and squares) have two recessive genes, *ff*. All of the carriers have one dominant gene and one recessive gene, *Ff*. All of the individuals without the trait have two dominant genes, *FF*.

It’s Your Turn

Please read each question carefully. For each multiple-choice question, circle the letter of the correct response.

1 A scientist is studying a plant’s hereditary information. Which part of the plant’s cells is the scientist most likely studying?

A the cell membrane

B the chromosomes

C the cell wall

D the chloroplasts

2 In dogs, fur length is a genetic trait. A dog has short fur. What is most likely true about the dog?

A Some of its ancestors had short fur.

B All of its ancestors had long fur.

C None of its offspring will have short fur.

D All of its offspring will have long fur.

3 A scientist wants to take a cell sample from a person. The scientist wants to take as few cells as possible, but still wants to have a copy of every gene in the person’s body. Which of these is the *smallest* sample the scientist can take and still have all the genes?

A several strands of hair

B two cells from the person’s heart

C at least 25 cells from the person’s muscles

D one skin cell

4 A scientist is studying the smallest units of hereditary information in human cells. The scientist is most likely studying

A chromosomes

B nuclei

C traits

D genes

5 **The males of a particular insect species have horns that they use to fight each other. One gene controls the length of a male's horns. The table below shows the horn lengths of males with different gene combinations.**

HORN LENGTHS AND GENE COMBINATIONS

Gene Combination	Horn Length
LL	long
SS	short
LS or *SL*	medium

Which of these statements is most likely true?

A The *L* gene is dominant, and the *S* gene is recessive.

B Horn length is not determined by dominant and recessive genes.

C The *S* gene is dominant, and the *L* gene is recessive.

D Both genes are dominant over a third gene that is hidden.

For this open-ended question, write your answers in the Punnett square and on the line.

6 **Stem length in pea plants is an inherited trait. The *T* gene is dominant. It codes for long stems. The *t* gene is recessive. It codes for short stems. Complete the Punnett square below for a cross of a *Tt* plant with a *tt* plant. Then, identify the percentage of the offspring that will have short stems.**

	T	*t*
t		
t		

__________% of the offspring will have short stems.