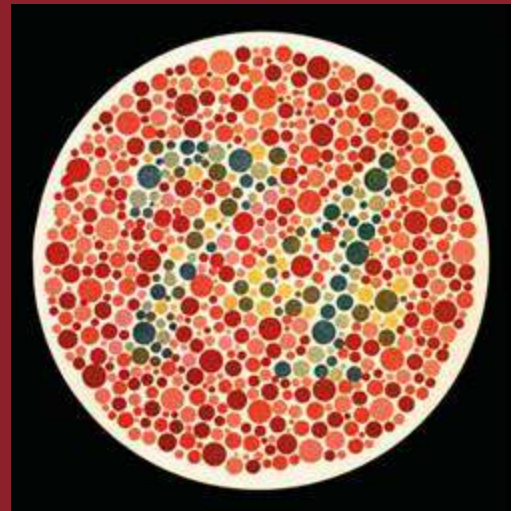


# 10

## *Genetics: Mendel and Beyond*



## 10 Genetics: Mendel and Beyond

Put the following words in their correct location in the sentences below.

crossing over

fertilization

meiosis

zygote

4

haploid

prophase I

diploid

testes

eggs

2

ovaries

sperm

46

puberty

gametes

23

metaphase I

DNA

chromosome

The process of sexual reproduction is specifically designed to ensure that there is genetic variation in offspring. Sex cells in females are called \_\_\_\_\_ and are manufactured in the \_\_\_\_\_, whereas male sex cells are called \_\_\_\_\_ and are manufactured in the \_\_\_\_\_. Male and female sex cells are collectively called \_\_\_\_\_. The process of \_\_\_\_\_ occurs in the reproductive organs of both males and females. This process reduces the chromosome number from \_\_\_\_\_ to \_\_\_\_\_. During this process, a special event called \_\_\_\_\_ occurs, where genetic material breaks off and exchanges with sister chromatids, thus allowing for genetic variation. This special event that prevents cloning occurs during a phase called \_\_\_\_\_. Although the process that makes sex cells is much like mitosis in normal body cells, there are several differences including the phase of \_\_\_\_\_, where chromosomes line up side by side, rather than in a straight line. Also, when sex cells are made, one cell divides to make \_\_\_\_\_ cells, then divides again to make \_\_\_\_\_ cells. In males, all of these cells become sperm, but in females, only one of these cells will become an egg. The process where an egg and sperm combine is called \_\_\_\_\_, and produces a new cell called a \_\_\_\_\_. A time in life where organisms become sexually active (able to produce offspring) is called \_\_\_\_\_.

## 10.1 What Are the Mendelian Laws of Inheritance?

People have been cross-breeding plants and animals for at least 5,000 years.

By the nineteenth century, plant breeding was widespread.

At the time, breeders worked under two assumptions about how inheritance works:

## 10.1 What Are the Mendelian Laws of Inheritance?

- Each parent contributes equally to offspring. (Correct.) Supported by reciprocal crosses, 1770s, by Kölreuter.
- Hereditary determinants blend in the offspring. (Incorrect.) It was thought that once hereditary elements had blended they could never be separated.
- Gregor Mendel's studies refuted this.
- Before genetics were understood, people thought that animals and plants could only be made bigger by feeding them more.

## 10.1 What Are the Mendelian Laws of Inheritance?

Mendel was an Austrian monk.

His studies in physics and mathematics were a strong influence on his use of quantitative experimental methods.

Over seven years, he made crosses with 24,034 plants.

## 10.1 What Are the Mendelian Laws of Inheritance?

His new theory of inheritance was published in 1866, but was largely ignored.

Most biologists at the time were not used to thinking in mathematical terms.

Even Darwin missed the significance of Mendel's work.

## Figure 10.1 Gregor Mendel and His Garden



**LIFE 8e, Figure 10.1**

## 10.1 What Are the Mendelian Laws of Inheritance?

By 1900, meiosis had been observed.

Three plant geneticists realized that chromosomes and meiosis provided a physical explanation for Mendel's results.



## 10.1 What Are the Mendelian Laws of Inheritance?

Mendel chose to work with the garden pea.

He could control pollination and fertilization—he could be sure of the parents of offspring.

The peas naturally *self-pollinate*.

## 10.1 What Are the Mendelian Laws of Inheritance?

**Character:** observable physical feature (e.g., flower color).

**Trait:** form of a character (e.g., purple flowers or white flowers).

A **heritable trait** is passed from parent to offspring.

## 10.1 What Are the Mendelian Laws of Inheritance?















Mendel looked for well-defined, **true-breeding** traits—the observed trait is the only one present for many generations.

True-breeding strains were isolated by inbreeding and selection.

He concentrated on seven traits.

Table 10.1

**TABLE 10.1****Mendel's Results from Monohybrid Crosses**

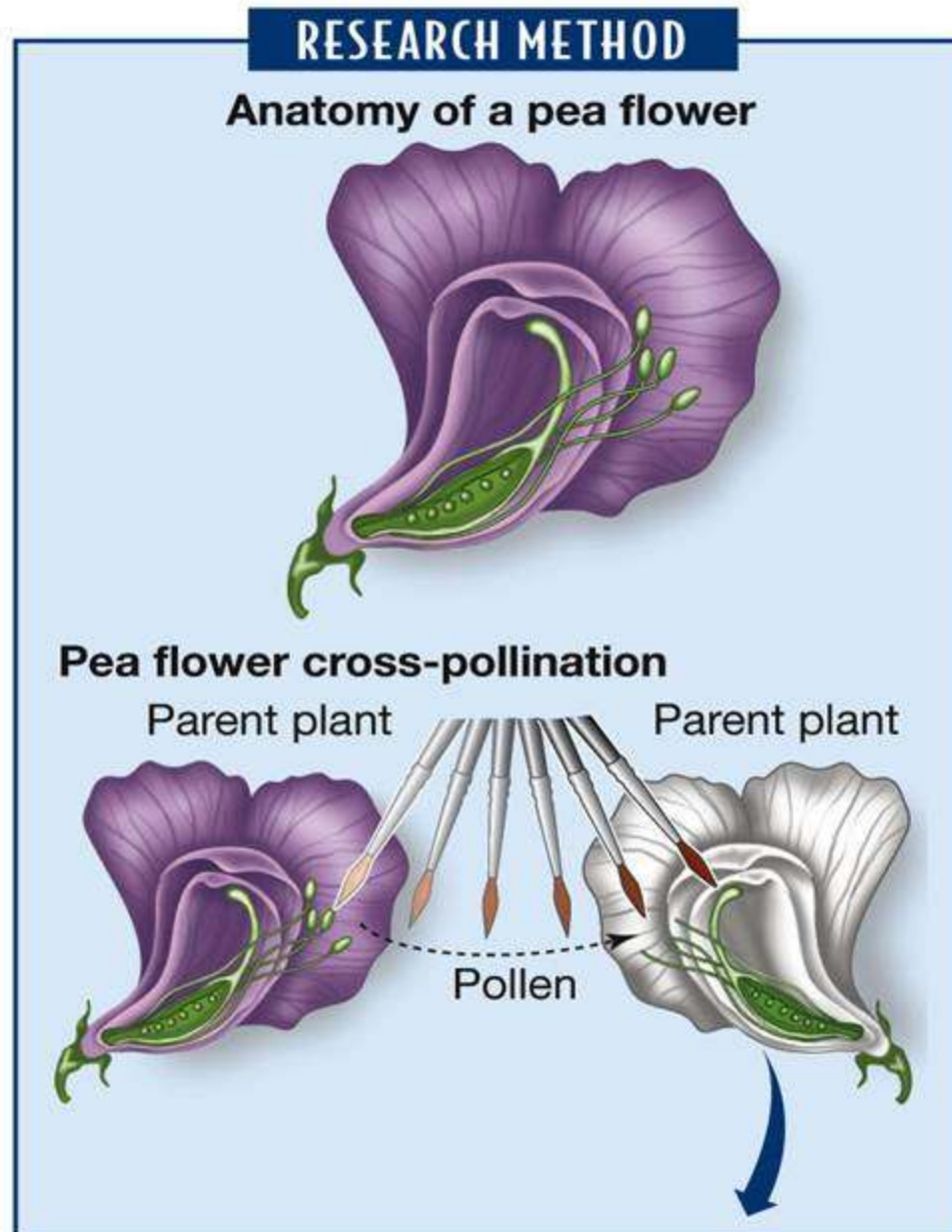
PARENTAL GENERATION PHENOTYPES		F <sub>2</sub> GENERATION PHENOTYPES			
DOMINANT	RECESSIVE	DOMINANT	RECESSIVE	TOTAL	RATIO
 Spherical seeds	× Wrinkled seeds 	5,474	1,850	7,324	2.96:1
 Yellow seeds	× Green seeds 	6,022	2,001	8,023	3.01:1
 Purple flowers	× White flowers 	705	224	929	3.15:1
 Inflated pods	× Constricted pods 	882	299	1,181	2.95:1
 Green pods	× Yellow pods 	428	152	580	2.82:1
 Axial flowers	× Terminal flowers 	651	207	858	3.14:1
 Tall stems (1 m)	× Dwarf stems (0.3 m) 	787	277	1,064	2.84:1

## 10.1 What Are the Mendelian Laws of Inheritance?

Mendel's crosses:

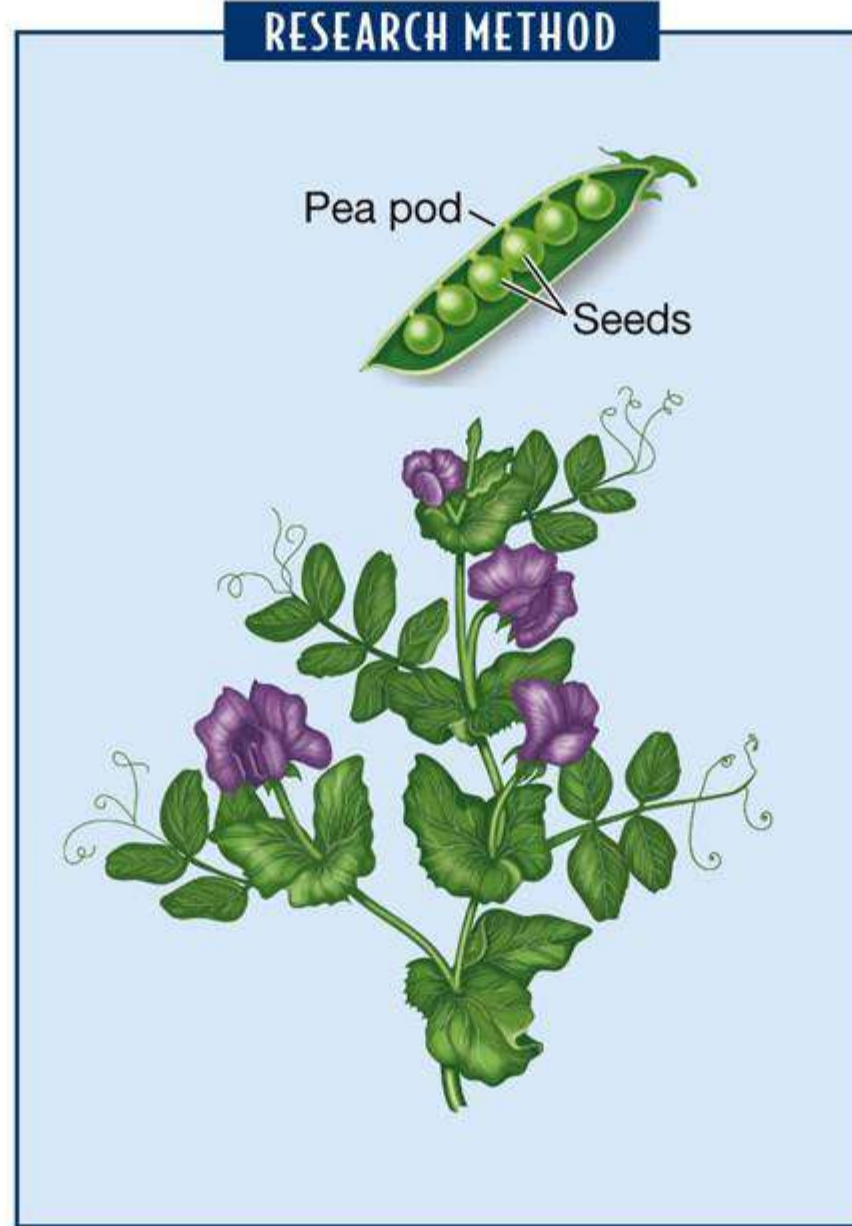
- Pollen from one parent was transferred to the stigma of the other parent.  
**Parental generation =  $P$ .**
- Resulting offspring = **first filial generation** or  $F_1$ .
- If  $F_1$  plants self pollinate, produce **second filial generation** or  $F_2$ .

## Figure 10.2 A Controlled Cross between Two Plants (Part 1)



**LIFE 8e, Figure 10.2 (Part 1)**

## Figure 10.2 A Controlled Cross between Two Plants (Part 2)



**LIFE 8e, Figure 10.2 (Part 2)**

## 10.1 What Are the Mendelian Laws of Inheritance?

Mendel's first experiment:

Crossed plants differing in just one trait ( $P$ ).

$F_1$  generation are *monohybrids*.















The monohybrids were then allowed to self pollinate to form the  $F_2$  generation: a **monohybrid cross**.

Mendel repeated this for all seven traits.



Table 10.1

**TABLE 10.1****Mendel's Results from Monohybrid Crosses**

PARENTAL GENERATION PHENOTYPES		F <sub>2</sub> GENERATION PHENOTYPES			
DOMINANT	RECESSIVE	DOMINANT	RECESSIVE	TOTAL	RATIO
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## 10.1 What Are the Mendelian Laws of Inheritance?

One trait of each pair disappeared in the  $F_1$  generation and reappeared in the  $F_2$ —these traits are *recessive*.

The trait that appears in the  $F_1$  is the *dominant* trait.

The ratio of dominant to recessive in the  $F_2$  was about 3:1.

## 10.1 What Are the Mendelian Laws of Inheritance?

Reciprocal crosses yielded the same results: it made no difference which parent contributed pollen.

The idea that each parent contributes equally was supported.

## 10.1 What Are the Mendelian Laws of Inheritance?

The blending theory was not supported by Mendel's crosses.

Mendel proposed that the heritable units were *discrete particles*—the **particulate theory**.

Each plant has two particles for each character, one from each parent.

Figure 10.3 Mendel's Monohybrid Experiments (Part 1)

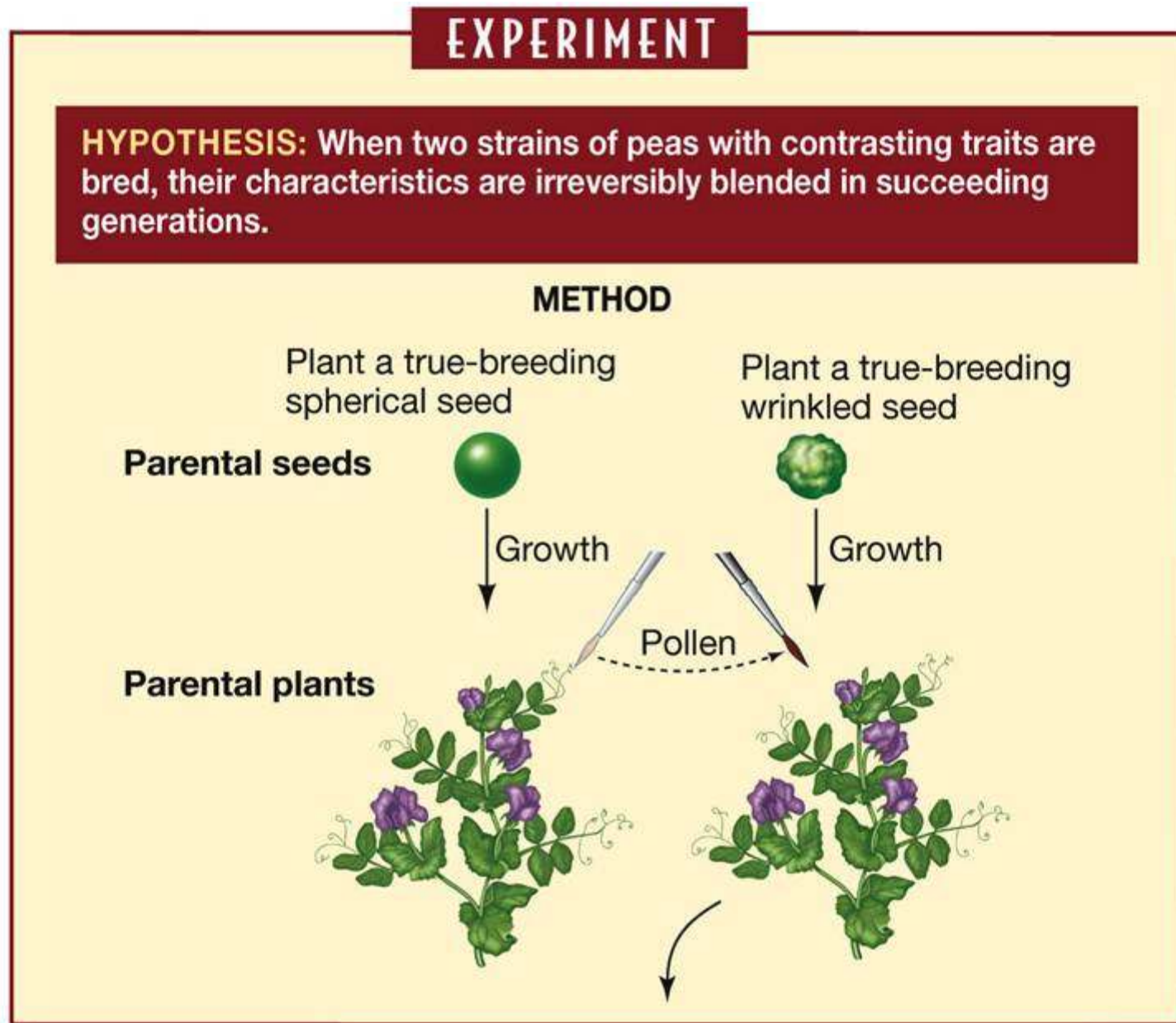
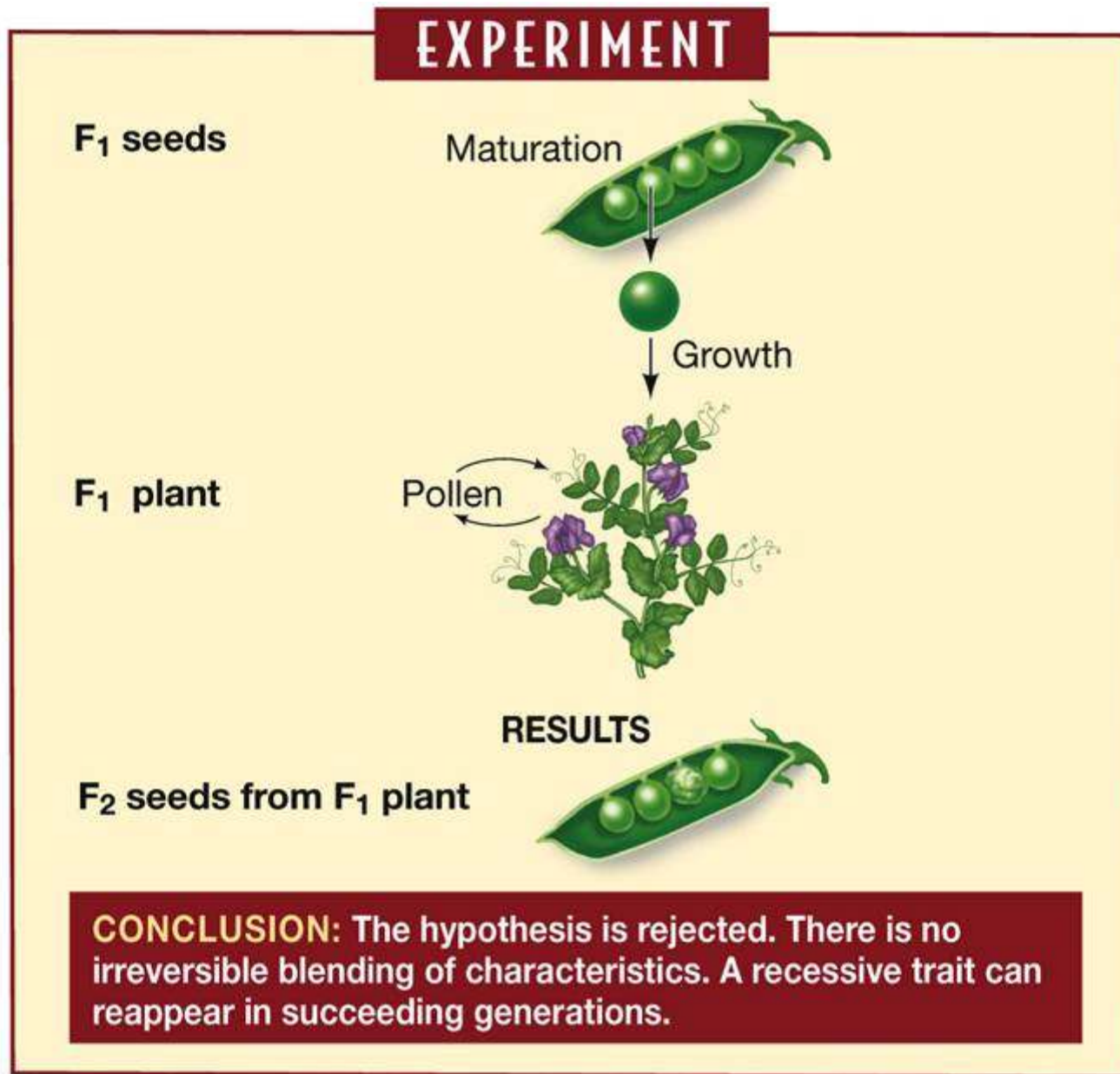


Figure 10.3 Mendel's Monohybrid Experiments (Part 2)



## 10.1 What Are the Mendelian Laws of Inheritance?

Mendel also concluded that each gamete contains only one particle (or unit), but the zygote contains two—because it is produced from the fusion of two gametes.

The “particles” are now called **genes**.

The totality of all genes in an organism is the **genome**.

## 10.1 What Are the Mendelian Laws of Inheritance?

The true-breeding plants in the P generation had two identical copies of the particle (gene) for each character.

Example: spherical  $SS$ ; wrinkled  $ss$

Gametes from  $SS$  will have one  $S$

Gametes from  $ss$  will have one  $s$

Offspring ( $F_1$ ) will be  $Ss$

$S$  is dominant;  $s$  is not expressed in  $F_1$



## 10.1 What Are the Mendelian Laws of Inheritance?

**Alleles:** different forms of a gene

True-breeding individuals have two copies of the same allele—they are **homozygous** for the allele (e.g., *ss*).

**Heterozygous** individuals have two different alleles (e.g., *Ss*).

## 10.1 What Are the Mendelian Laws of Inheritance?

**Phenotype:** physical appearance of an organism (e.g., spherical seeds).

**Genotype:** the genetic makeup (e.g., Ss).

Spherical seeds can be the result of two different genotypes—SS or Ss.

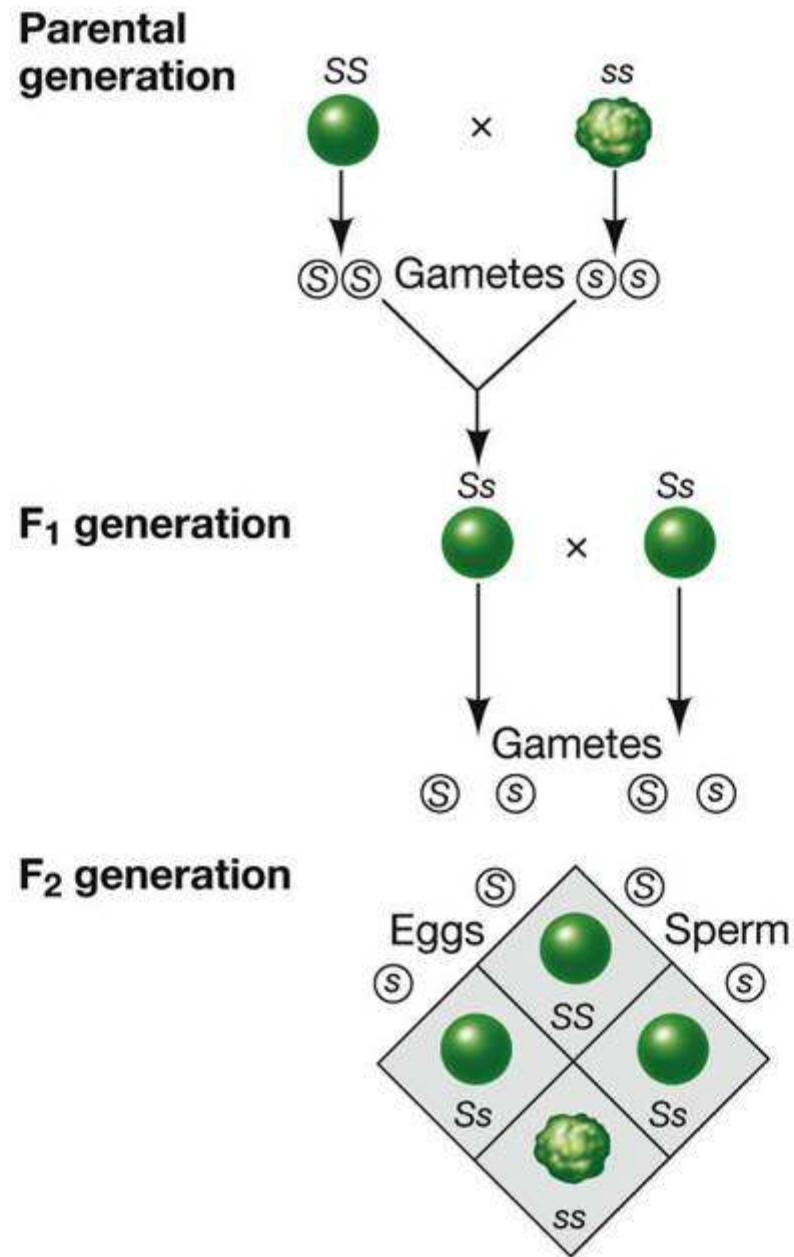
## 10.1 What Are the Mendelian Laws of Inheritance?

### *Mendel's first law*

**The Law of Segregation:** the two copies of a gene separate when an individual makes gametes.

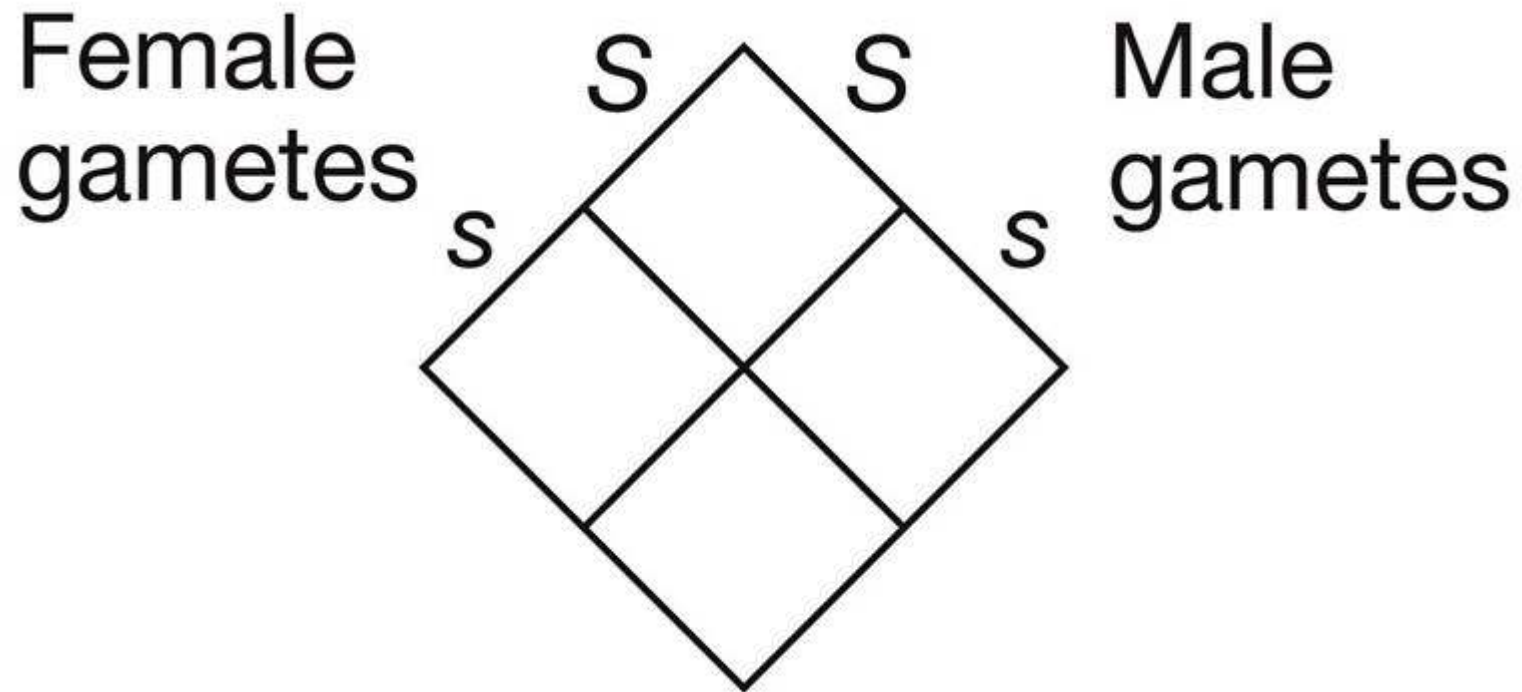
When the  $F_1$  self-pollinates, there are three ways to get the dominant trait (e.g., spherical), only one way to get the recessive (wrinkled)—resulting in the 3:1 ratio.

Figure 10.4 Mendel's Explanation of Inheritance



## 10.1 What Are the Mendelian Laws of Inheritance?

Allele combinations can be predicted using a **Punnett square**:



Practice Punnett Squares for Monohybrid Crosses (genetics example)

## 10.1 What Are the Mendelian Laws of Inheritance?

A gene is a sequence on a DNA molecule that resides at a particular site on a chromosome—the **locus**—and encodes a particular character.

Genes are expressed as proteins with particular functions.

Different alleles of a gene separate during meiosis.

## Figure 10.5 Meiosis Accounts for the Segregation of Alleles (Part 1)

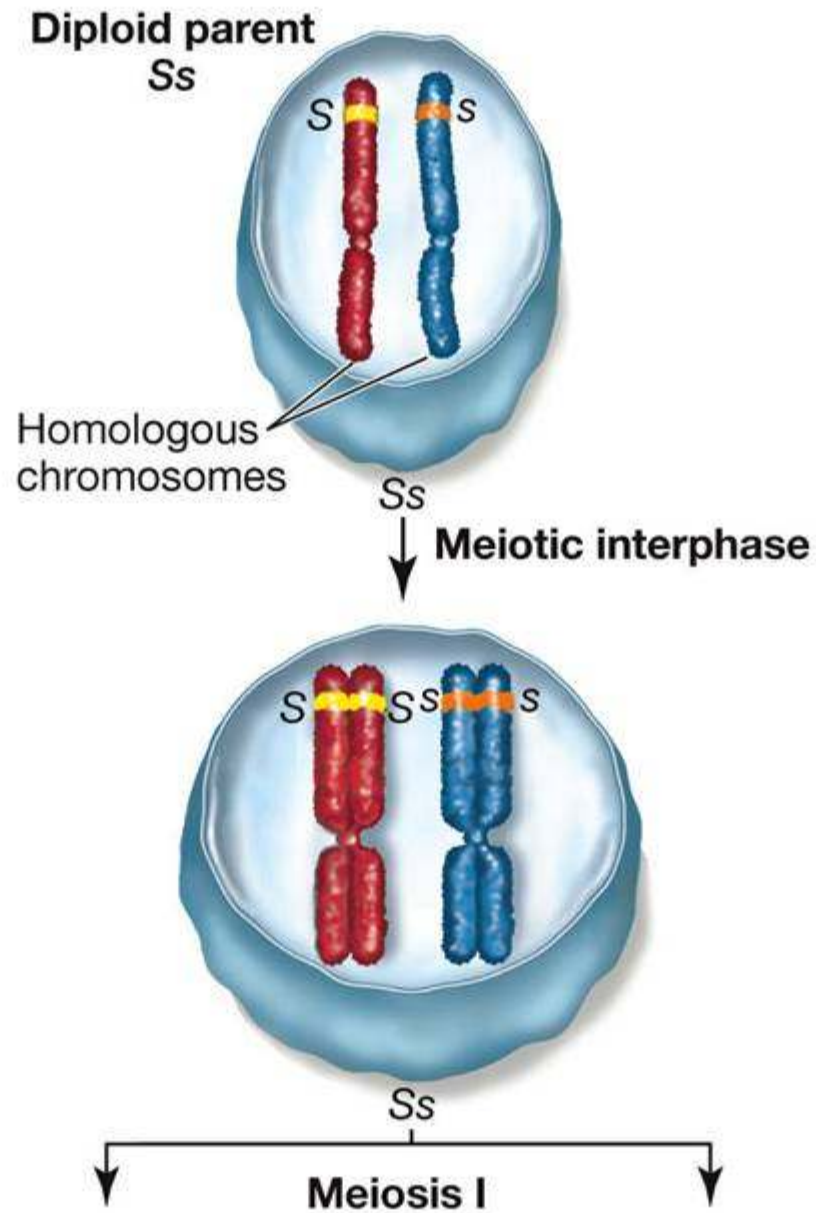
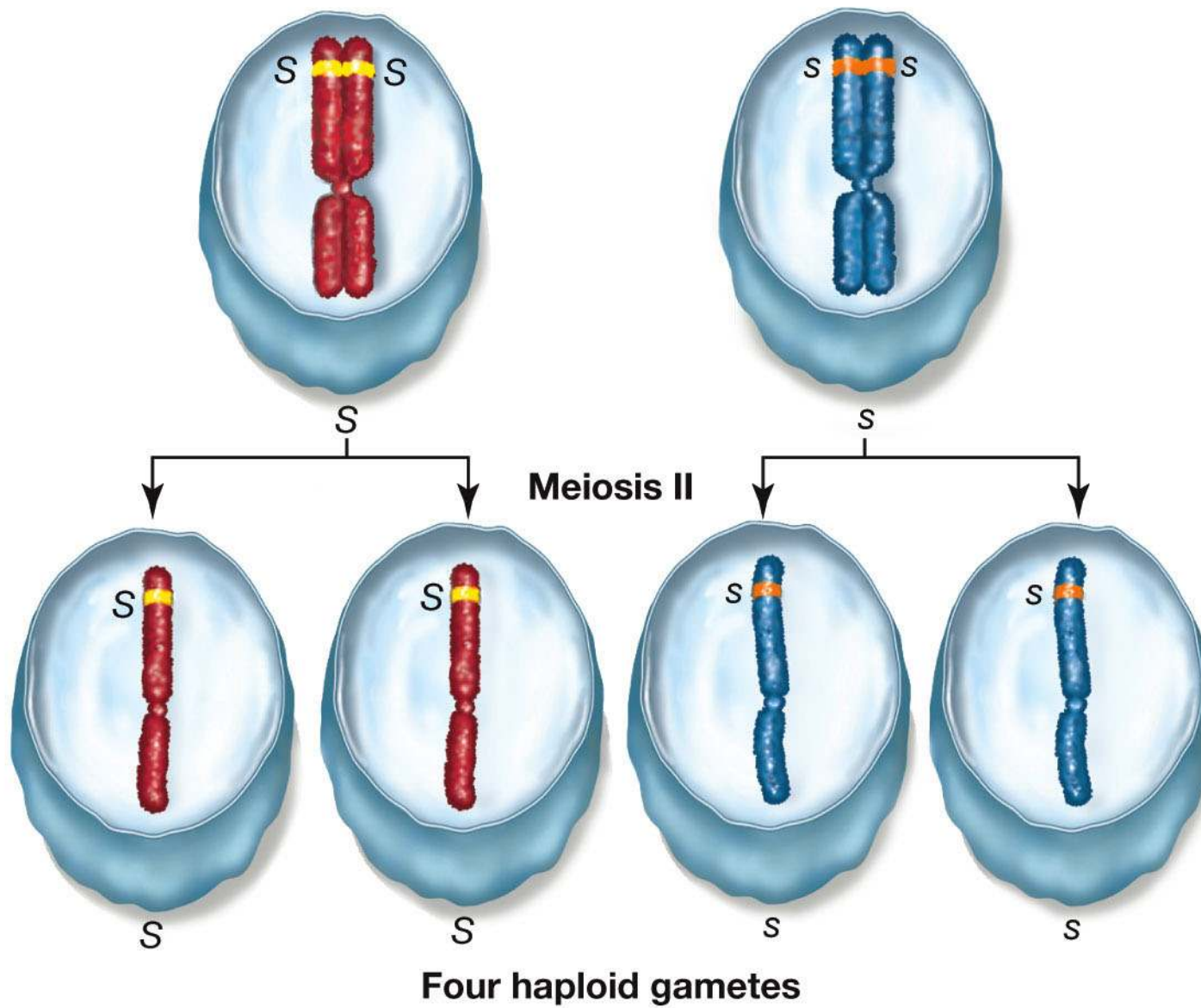


Figure 10.5 Meiosis Accounts for the Segregation of Alleles (Part 2)





## 10.1 What Are the Mendelian Laws of Inheritance?

Mendel tested his hypothesis by doing **test crosses**:

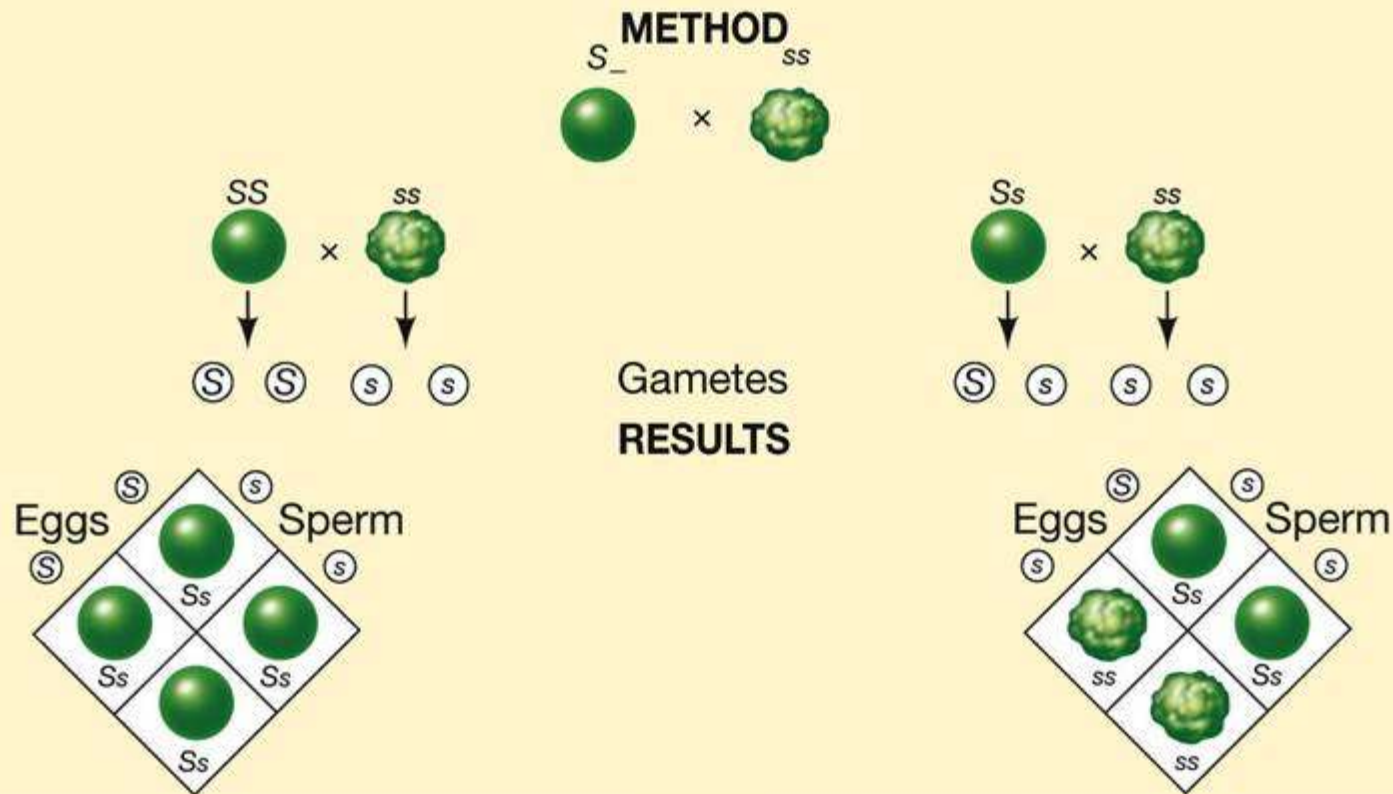
- Determines whether an individual is homozygous or heterozygous for a trait by crossing it with the homozygous recessive.

Mendel crossed the  $F_1$  with known homozygote's (e.g., wrinkled or  $ss$ ).

Figure 10.6 Homozygous or Heterozygous?

## EXPERIMENT

**HYPOTHESIS:** A test cross can reveal whether an organism is homozygous or heterozygous.



**CONCLUSION:** The plant being tested is homozygous.

**CONCLUSION:** The plant being tested is heterozygous.

## 10.1 What Are the Mendelian Laws of Inheritance?

Mendel's next experiment:

Crossing peas that differed in two characters—seed shape and seed color.

True-breeding parents:

*SSYY*—spherical yellow seeds

*ssyy*—wrinkled green seeds

## 10.1 What Are the Mendelian Laws of Inheritance?

$F_1$  generation is  $SsYy$ —all spherical yellow.

Crossing (self-pollinating) the  $F_1$  generation is a **dihybrid cross**.

Mendel asked whether, in the gametes produced by  $SsYy$ , the traits would be linked, or segregate independently.

Practice Punnett Squares for Dihybrid Crosses (genetics example)

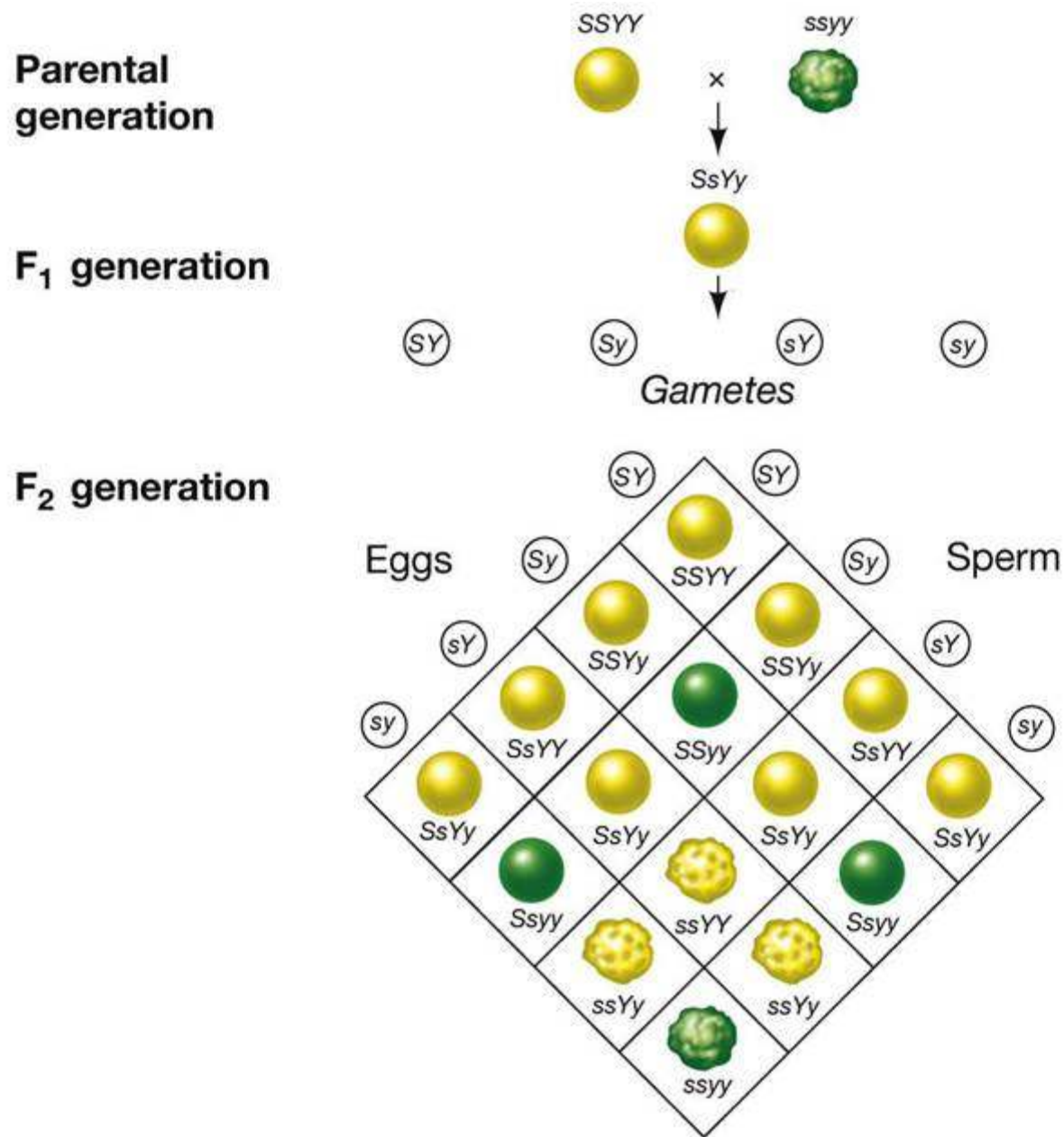
## 10.1 What Are the Mendelian Laws of Inheritance?

If linked, gametes would be  $SY$  or  $sy$ ;  $F_2$  would have three times more spherical yellow than wrinkled green.

If independent, gametes could be  $SY$ ,  $sy$ ,  $Sy$ , or  $sY$ .  $F_2$  would have nine different genotypes; phenotypes would be in 9:3:3:1 ratio.

Results in **recombinant** phenotypes.

Figure 10.7 Independent Assortment



## 10.1 What Are the Mendelian Laws of Inheritance?

*Mendel's second law*

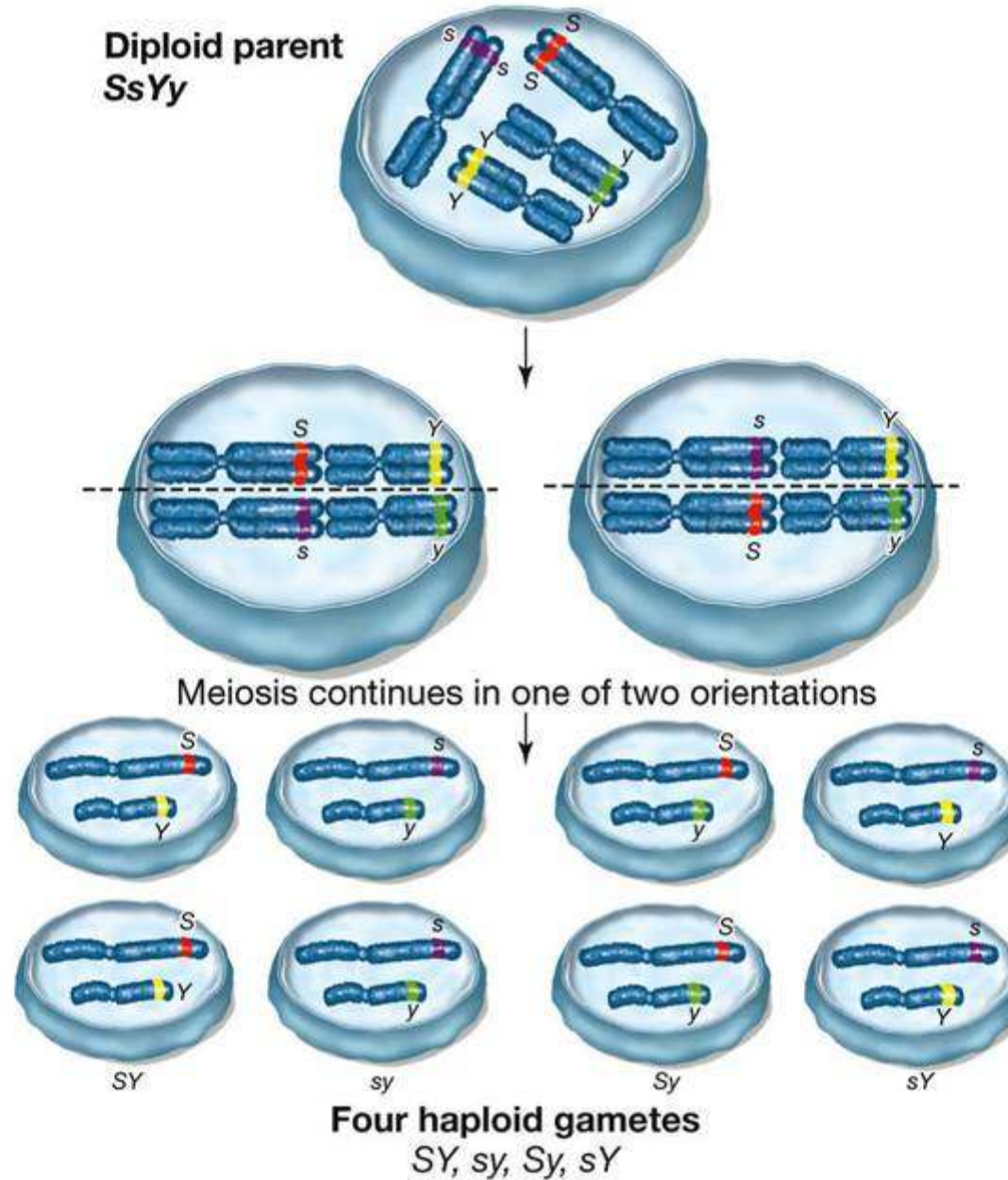
### **The Law of Independent Assortment:**

Alleles of different genes assort independently during gamete formation.

Doesn't always apply to genes on the same chromosome; but chromosomes do segregate independently.



Figure 10.8 Meiosis Accounts for Independent Assortment of Alleles





## 10.1 What Are the Mendelian Laws of Inheritance?

One of Mendel's contributions to genetics was the use of mathematical analyses—the rules of statistics and probability.

## 10.1 What Are the Mendelian Laws of Inheritance?

### Probability:

- If an event is certain to happen, probability = 1
- If an event cannot possibly happen, probability = 0
- All other events have a probability between 0 and 1

## 10.1 What Are the Mendelian Laws of Inheritance?

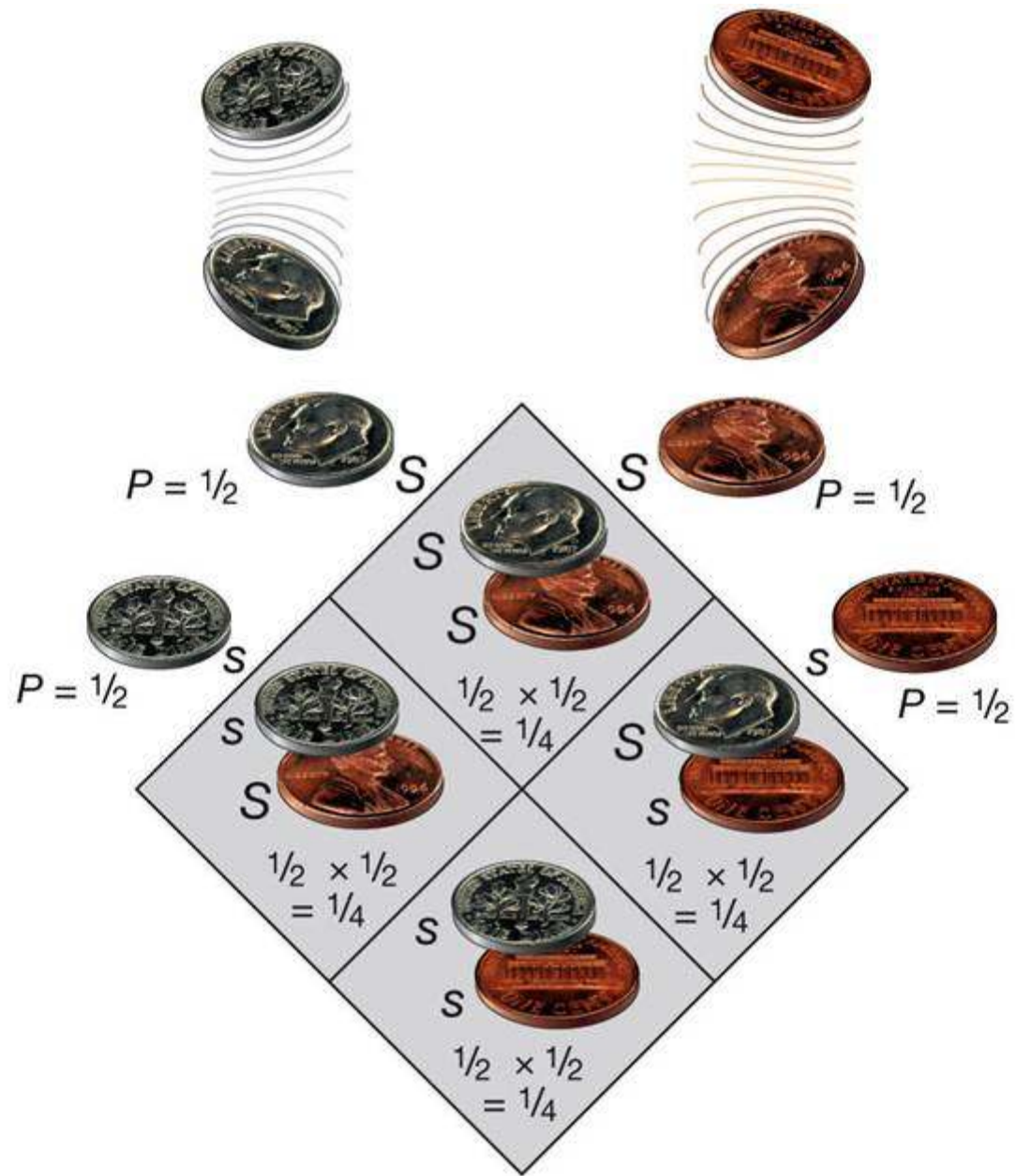
Probability of two independent events happening together: multiply the probabilities of the individual events.

Tossing two coins—probability that both will come up heads:

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

The multiplication rule.

Figure 10.9 Using Probability Calculations in Genetics



## 10.1 What Are the Mendelian Laws of Inheritance?

The probability of an event that can occur in two different ways is the sum of the individual probabilities.

In  $F_2$ , there are two ways to get a heterozygote; thus  $\frac{1}{4} + \frac{1}{4} = \frac{1}{2}$

The addition rule.

Result: 1:2:1 ratio of genotypes; 3:1 ratio of phenotypes

## 10.1 What Are the Mendelian Laws of Inheritance?

Dihybrid crosses:

Probability that  $F_2$  seed will be spherical  
is  $\frac{3}{4}$  = probability of heterozygote +  
probability of homozygote or  $\frac{1}{2} + \frac{1}{4} = \frac{3}{4}$

Joint probability that a seed will be  
spherical and yellow:  $\frac{3}{4} \times \frac{3}{4} = \frac{9}{16}$

## 10.1 What Are the Mendelian Laws of Inheritance?

Probability calculations and Punnett squares give the same results.

## 10.1 What Are the Mendelian Laws of Inheritance?

Human **pedigrees** can show Mendel's laws.

Humans have few offspring; pedigrees do not show the clear proportions that the pea plants showed.

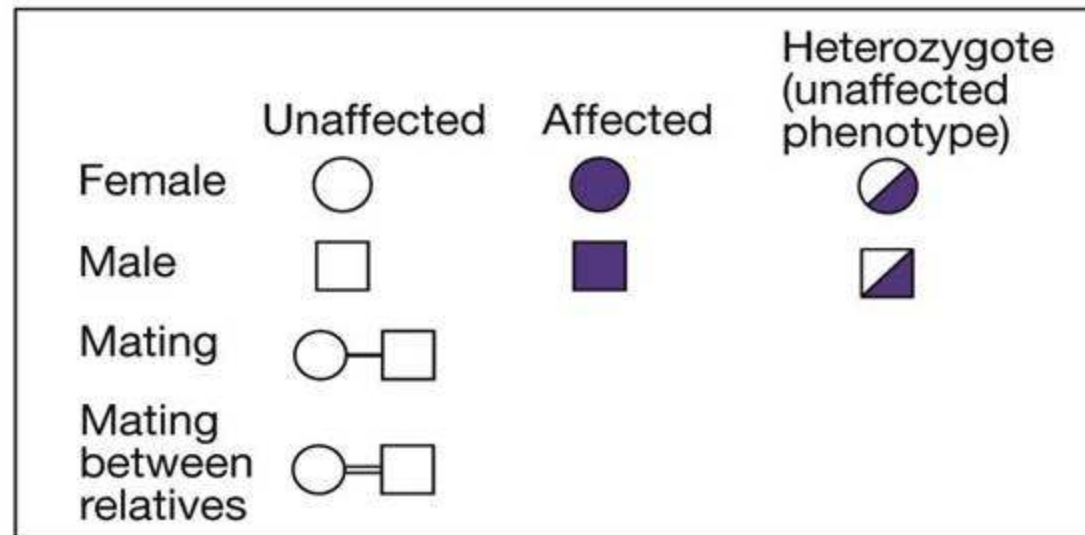
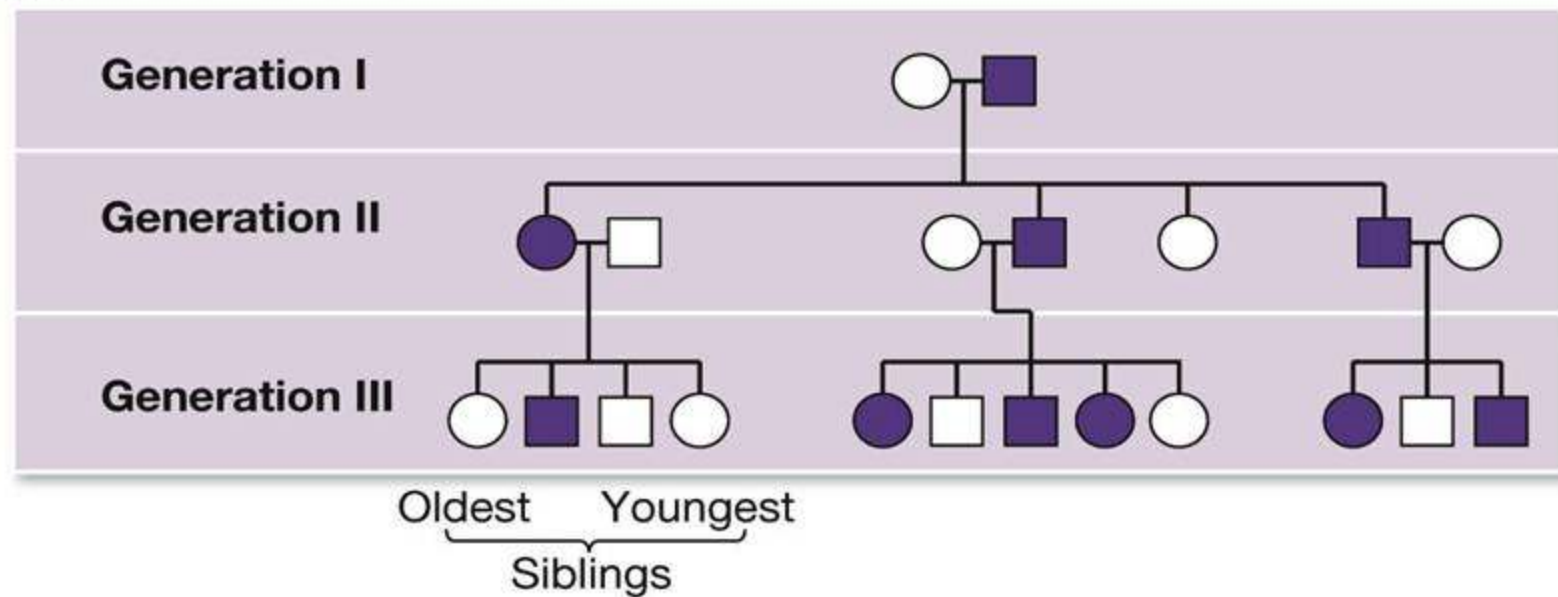


## 10.1 What Are the Mendelian Laws of Inheritance?

Geneticists use pedigrees to determine whether a rare allele is dominant or recessive.

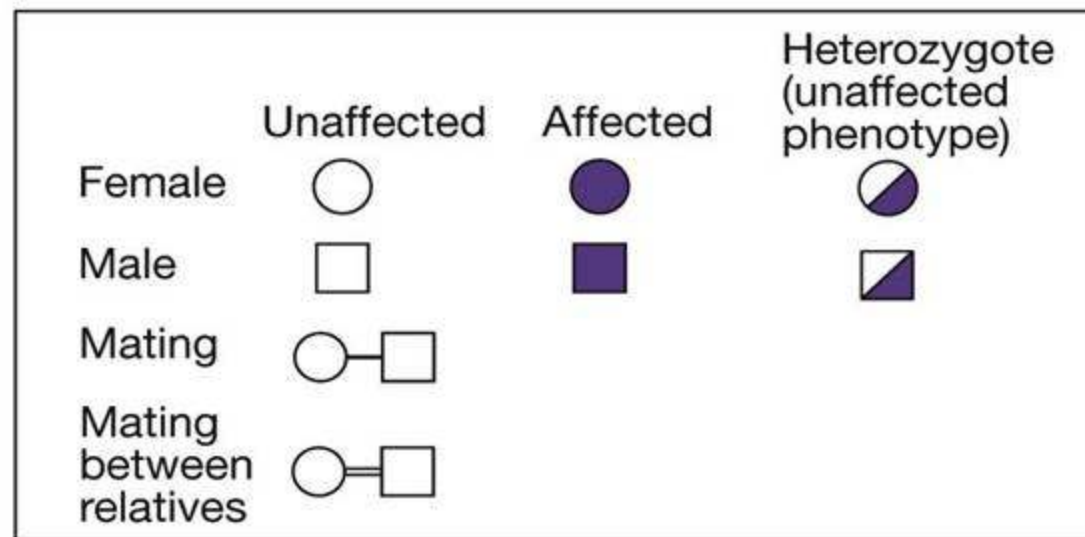
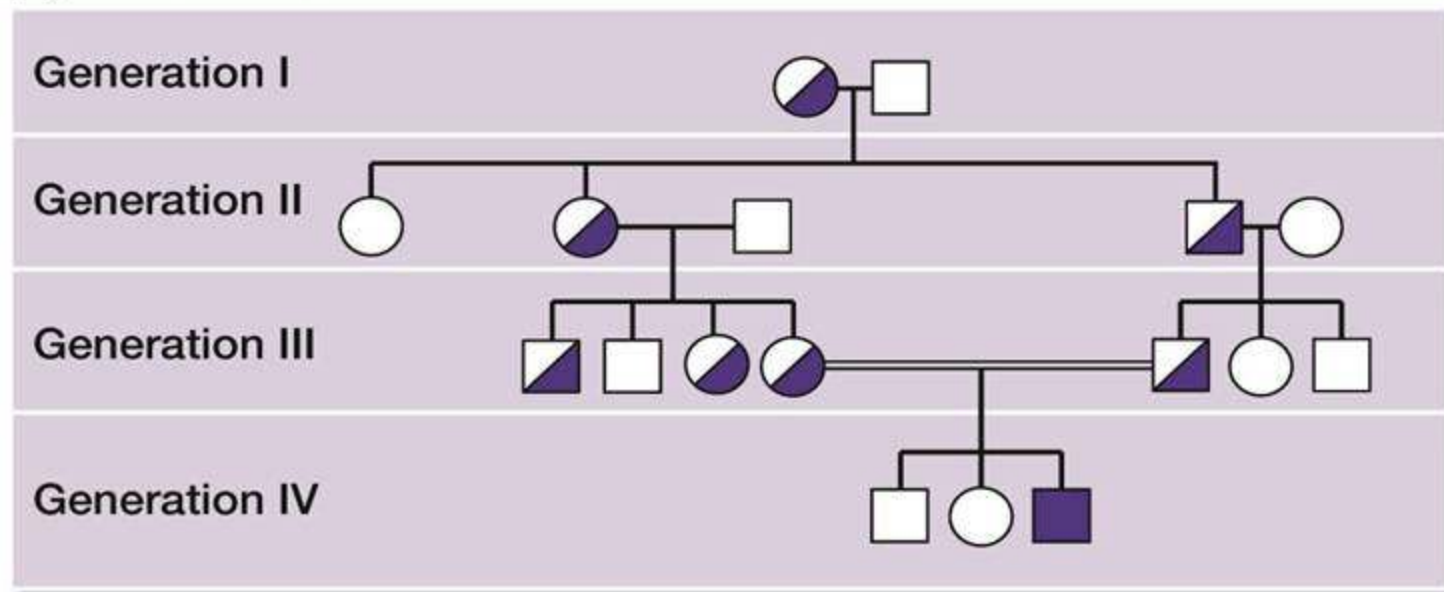
Figure 10.10 Pedigree Analysis and Inheritance (Part 1)

**(A) Dominant inheritance**



## Figure 10.10 Pedigree Analysis and Inheritance (Part 2)

### (B) Recessive inheritance



## 10.1 What Are the Mendelian Laws of Inheritance?

When there is a rare recessive phenotype in a family, there is usually marriage of relatives.

If a recessive allele is rare in the general population, it is unlikely that two people that marry will both carry it unless they are related (e.g., cousins).

## 10.2 How Do Alleles Interact?

Different alleles arise through **mutation**: rare, stable, inherited changes in the genetic material.

**Wild type**: allele present in most of the population. Other alleles are *mutant alleles*.

Locus with wild-type allele present less than 99% of the time is **polymorphic**.

## 10.2 How Do Alleles Interact?

A given gene may have more than two alleles.

Example: coat color in rabbits

Multiple alleles increase the number of possible phenotypes.

## Can you do Genetics?

- In humans, tongue rolling is a dominant trait, those with the recessive condition cannot roll their tongues. Bob can roll his tongue, but his mother could not. He is married to Sally, who cannot roll her tongue. What is the probability that their first born child will not be able to roll his tongue?
- An organism with the genotype  $AaBbCCdd$  is crossed with one that is  $AAbbccDd$ . What are the odds of having an offspring with the genotype  $AabbCcDd$ . In this problem, do not use punnet squares. Solve the problem using math and statistics and make sure you show all work.

Figure 10.11 Inheritance of Coat Color in Rabbits

Possible genotypes	$CC, Cc^{ch}, Cc^h, Cc$	$c^{ch}c^{ch}$	$c^{ch}c^h, c^hc$	$c^hc^h, c^hc$	$cc$
Phenotype	Dark gray	Chinchilla	Light gray	Point restricted	Albino



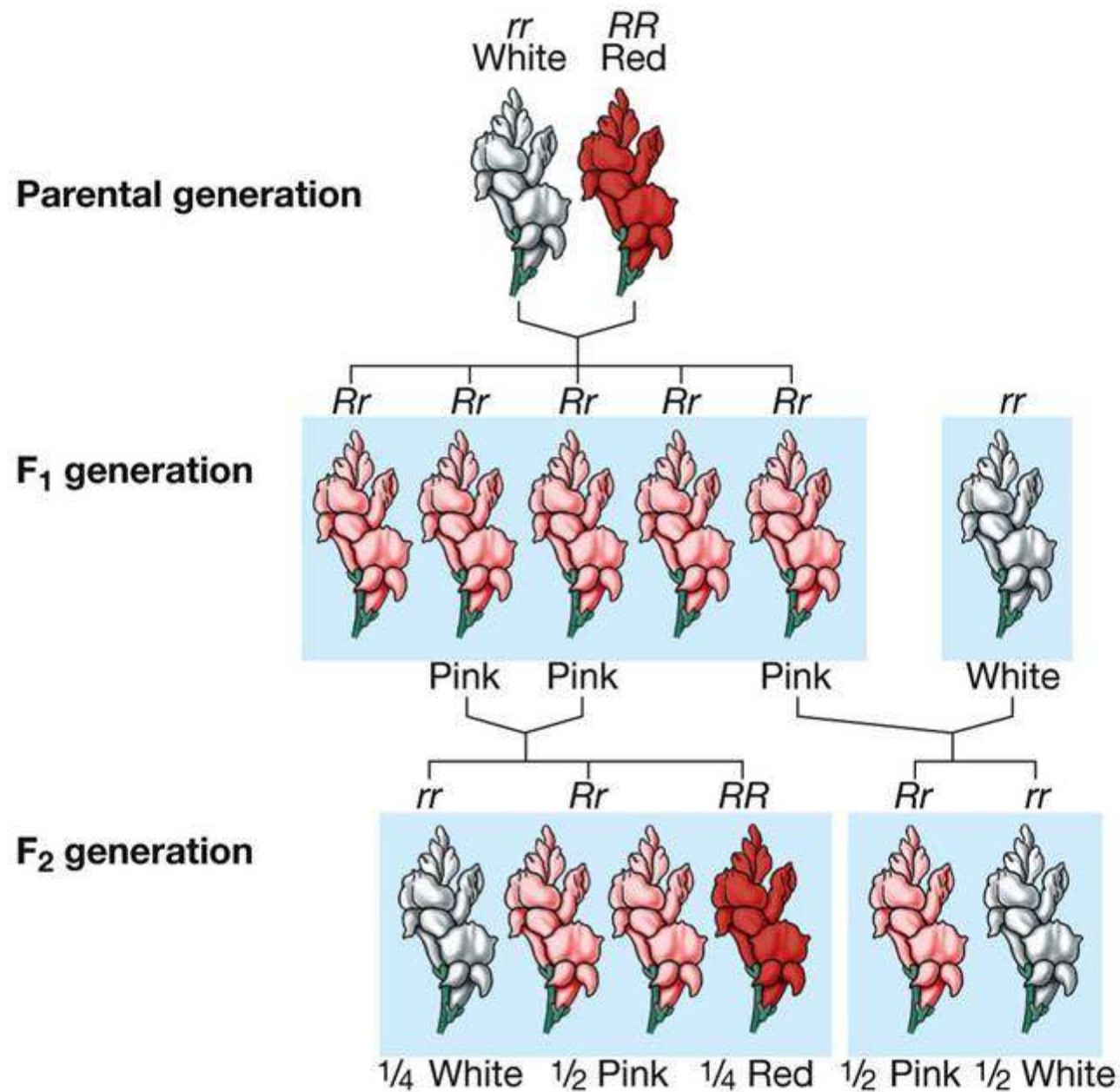


## 10.2 How Do Alleles Interact?

Some alleles are neither dominant nor recessive—heterozygote has an intermediate phenotype: **incomplete dominance**.

Example: snapdragons

Figure 10.12 Incomplete Dominance Follows Mendel's Laws

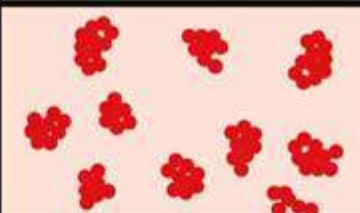

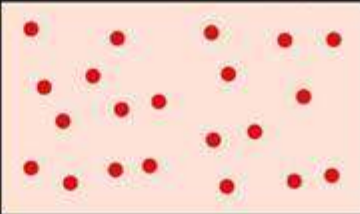
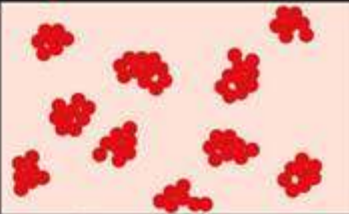






## 10.2 How Do Alleles Interact?

Codominance: two alleles at one locus produce phenotypes that are both present in the heterozygote.

Example: ABO blood group system—three alleles at one locus.

Figure 10.13 ABO Blood Reactions Are Important in Transfusions

Blood type of cells	Genotype	Antibodies made by body	Reaction to added antibodies	
			Anti-A	Anti-B
A	$I^A I^A$ or $I^A i^O$	Anti-B		
B	$I^B I^B$ or $I^B i^O$	Anti-A		
AB	$I^A I^B$	Neither anti-A nor anti-B		
O	$i^O i^O$	Both anti-A and anti-B		

## 10.2 How Do Alleles Interact?

A single allele can have multiple effects:  
**pleiotropic.**

Example: allele for coloration pattern in Siamese cats; the same allele results in crossed eyes—both result from the same protein.

## 10.3 How Do Genes Interact?

**Epistasis:** phenotypic expression of one gene is influenced by another gene.

Example: coat color in Labrador retrievers.

Allele **B** (black) dominant to **b** (brown)

Allele **E** (pigment deposition) is dominant to **e** (no pigment deposition—yellow)

## Figure 10.14 Genes May Interact Epistatically



(A) Black labrador ( $B\_E\_$ )



(B) Chocolate labrador ( $bbE\_$ )



(C) Yellow labrador ( $\_ \_ ee$ )

## 10.3 How Do Genes Interact?

**Inbreeding:** mating among close relatives; can result in offspring of low quality.

Close relatives tend to have the same recessive alleles.



## 10.3 How Do Genes Interact?

A cross between two different true-breeding homozygotes can result in offspring with stronger, larger phenotypes: *hybrid vigor* or **heterosis**.

First discovered with corn by G.H. Shull.

Figure 10.15 Hybrid Vigor in Corn



Parent

Parent

Hybrid offspring

**LIFE 8e, Figure 10.15**

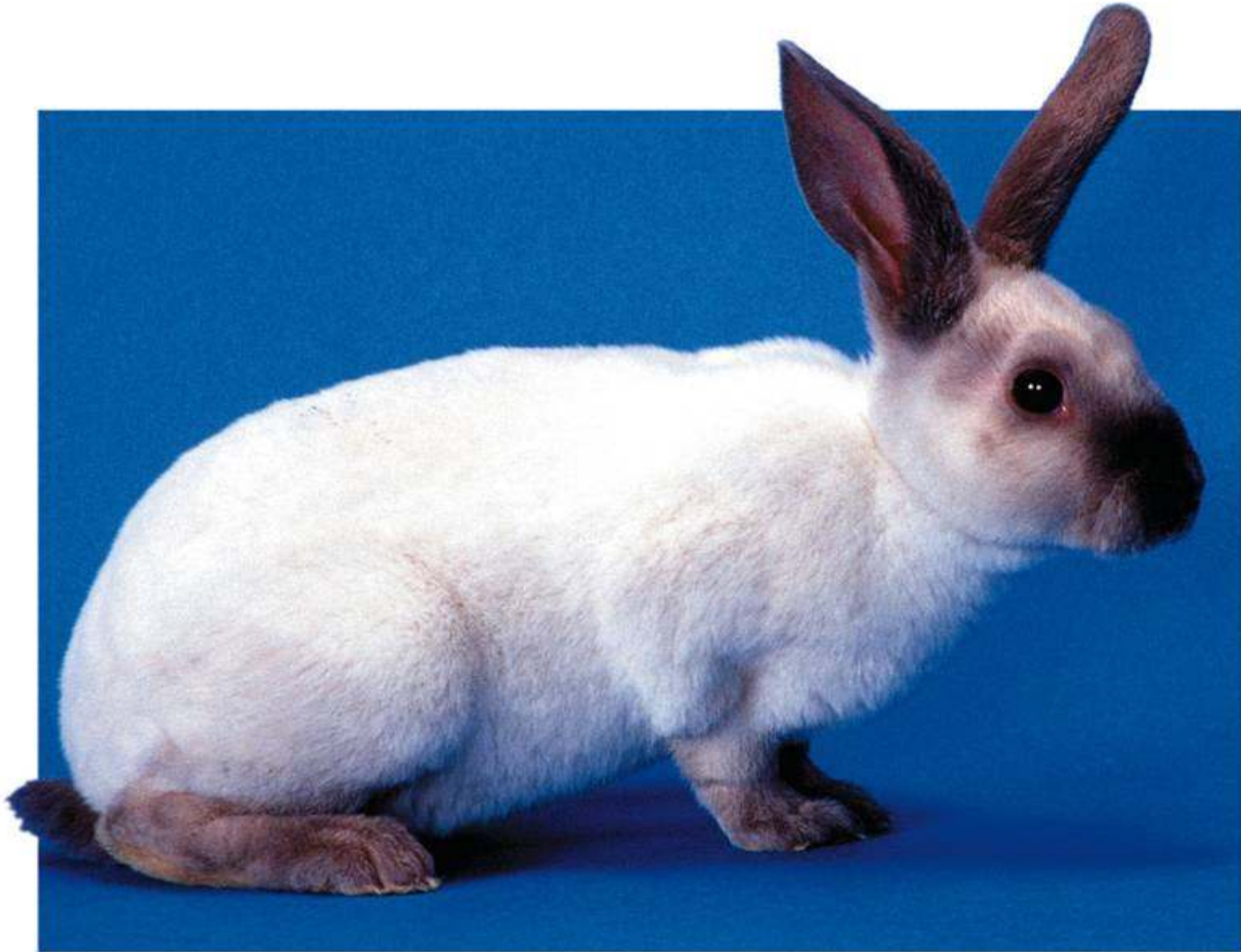
## 10.3 How Do Genes Interact?

Environment also affects phenotype.

Light, temperature, nutrition, etc., can affect expression of the genotype.

Siamese cats and certain rabbit breeds—enzyme that produces dark fur is inactive at higher temperatures.

Figure 10.16 The Environment Influences Gene Expression



**LIFE 8e, Figure 10.16**

## 10.3 How Do Genes Interact?

Effects of genes and environment:

- **Penetrance:** proportion of individuals with a certain genotype that show the phenotype.
- **Expressivity:** degree to which genotype is expressed in an individual.

## 10.3 How Do Genes Interact?

Mendel's characters were discrete and **qualitative**.

For more complex characters, phenotypes vary continuously over a range—**quantitative** variation, or *continuous*.

Quantitative variation is usually due to both genes and environment.



Figure 10.17 Quantitative Variation



**LIFE 8e, Figure 10.17**

## 10.3 How Do Genes Interact?

Genes that determine these complex characters: **quantitative trait loci**.

Identifying these loci can help improve crop yields, understand disease susceptibility and behavior, etc.



## 10.4 What Is the Relationship between Genes and Chromosomes?

Much genetic research has been done with the fruit fly *Drosophila melanogaster*.

Beginning in 1909 in Thomas Hunt Morgan's lab at Columbia—the “fly room.”

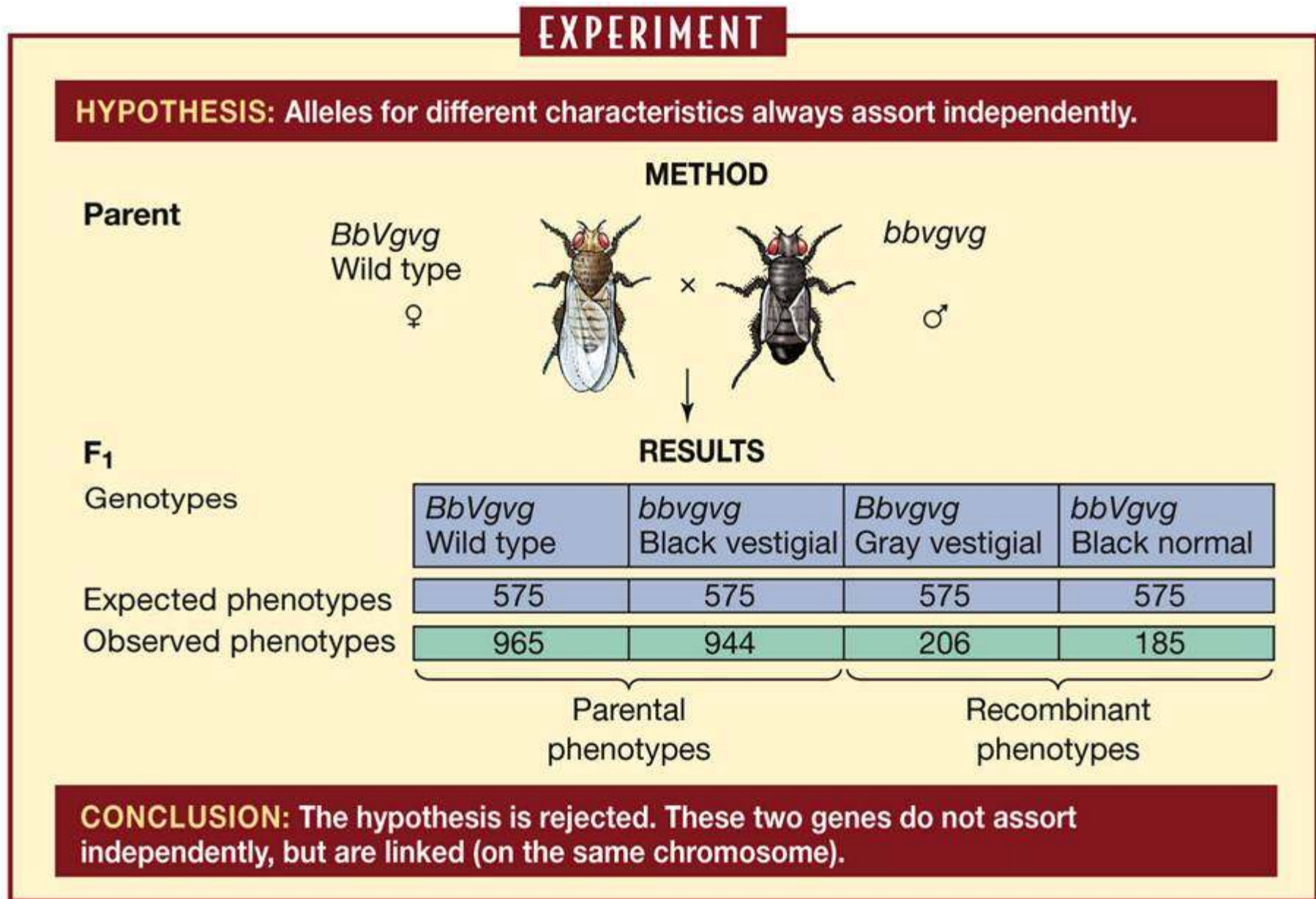
## 10.4 What Is the Relationship between Genes and Chromosomes?

Some crosses performed with *Drosophila* did not yield expected ratios according to the law of independent assortment.

Some genes were inherited together; the two loci were on the same chromosome, or linked.

All the loci on a chromosome form a **linkage group**.

Figure 10.18 Some Alleles Do Not Assort Independently



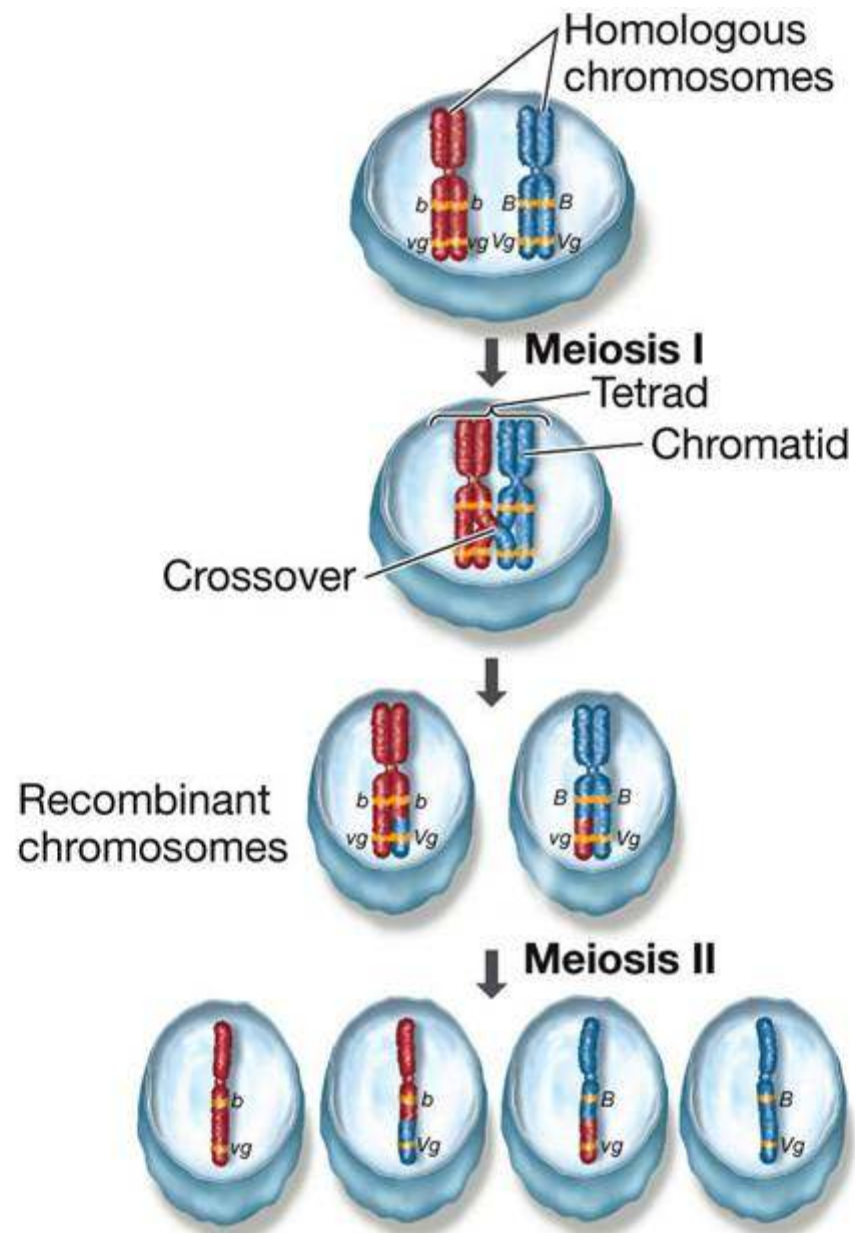
## 10.4 What Is the Relationship between Genes and Chromosomes?

Absolute linkage is rare.

Genes may recombine during prophase I of meiosis by crossing over.

Chromosomes exchange corresponding segments. The exchange involves two chromatids in the tetrad; both chromatids become recombinant.

Figure 10.19 Crossing Over Results in Genetic Recombination



## 10.4 What Is the Relationship between Genes and Chromosomes?

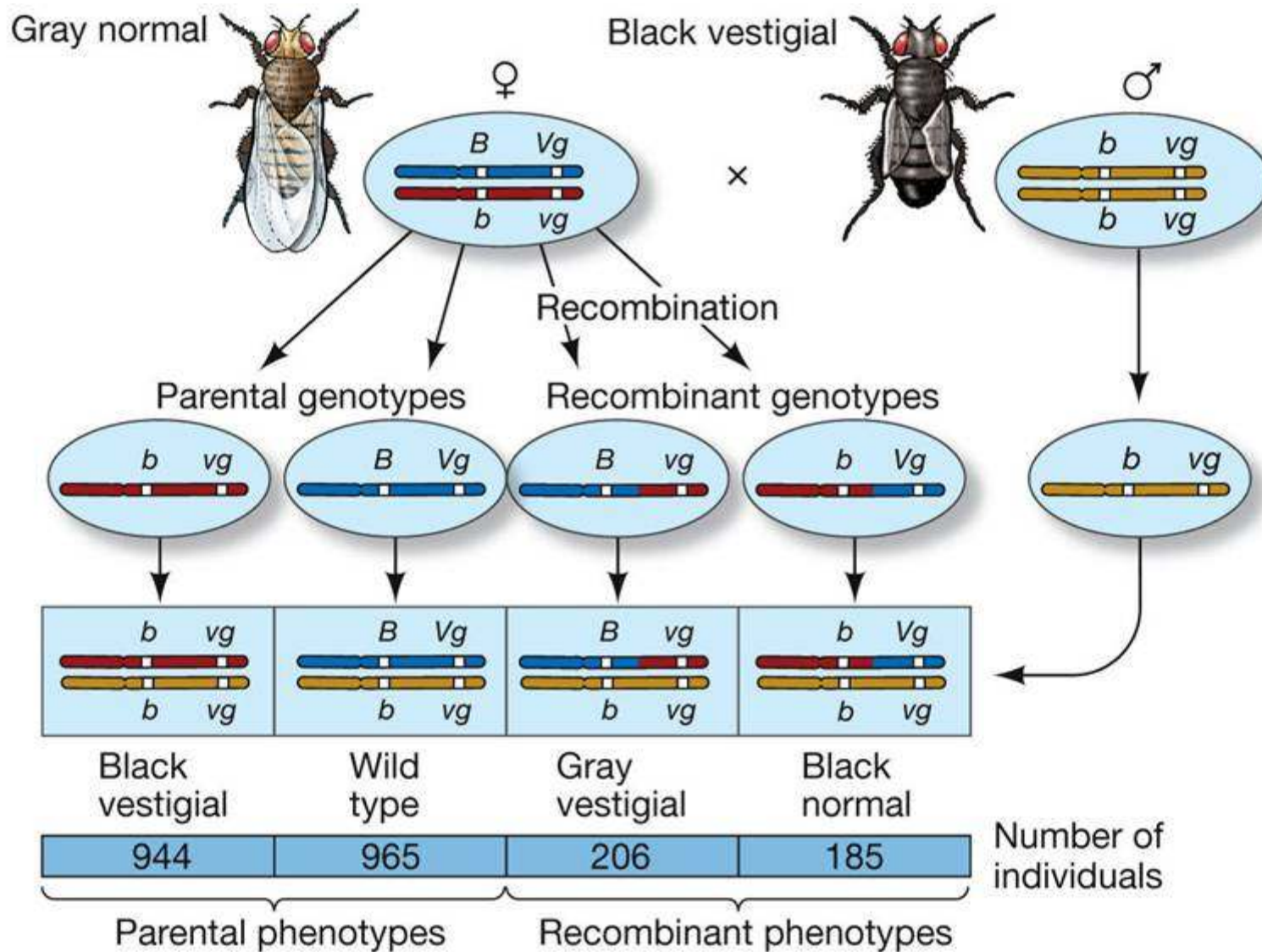
Recombinant offspring phenotypes (non-parental) appear in **recombinant frequencies**:

Divide number of recombinant offspring by total number of offspring.

Recombinant frequencies are greater for loci that are farther apart.



Figure 10.20 Recombinant Frequencies



$$\text{Recombinant frequency} = \frac{391 \text{ recombinants}}{2,300 \text{ total offspring}} = 0.17$$

## 10.4 What Is the Relationship between Genes and Chromosomes?

Recombinant frequencies can be used to make **genetic maps** showing the arrangement of genes along a chromosome.

Distance between genes = **map unit** = recombinant frequency of 0.01.

Map unit also called a **centimorgan (cM)**



Figure 10.21 Steps toward a Genetic Map

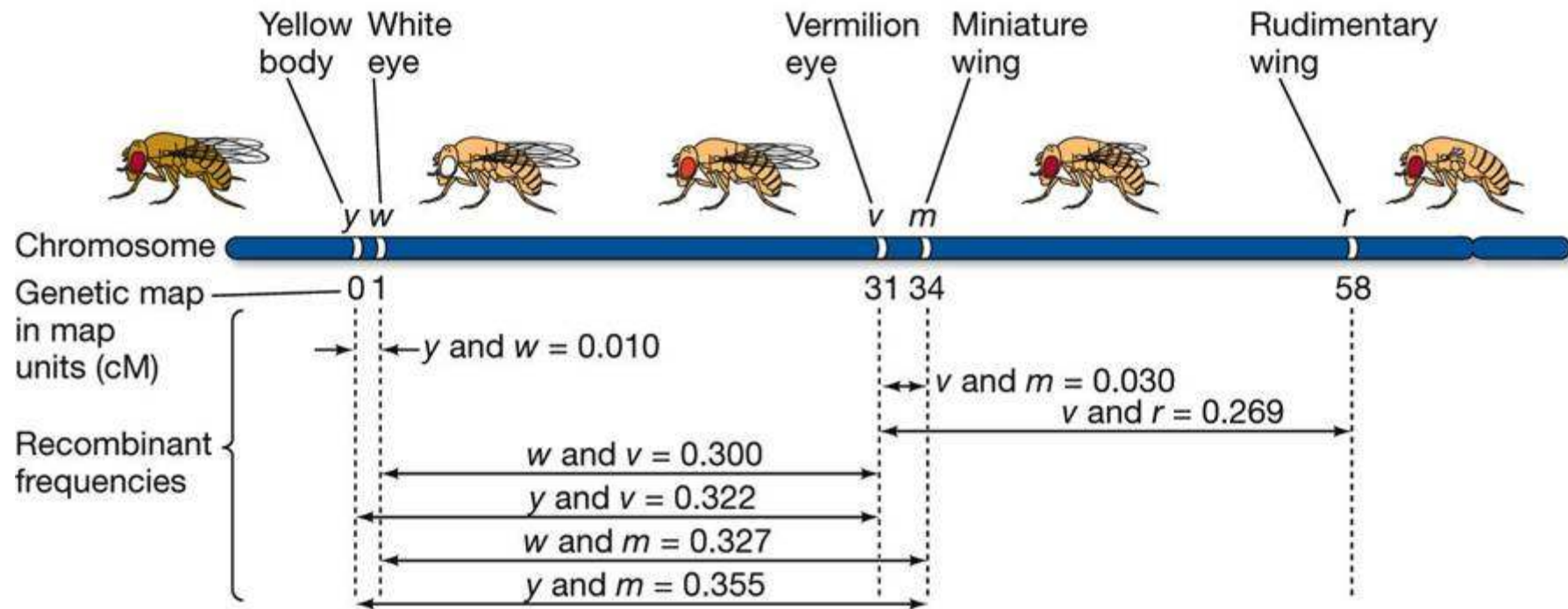


Figure 10.22 Map These Genes (Part 1)

- 1** At the outset, we have no idea of the individual distances between the genes, and there are several possible sequences (*a-b-c*, *a-c-b*, *b-a-c*).



We make a cross  $AABB \times aabb$ , and obtain an  $F_1$  generation with a genotype  $AaBb$ . We test cross these  $AaBb$  individuals with  $aabb$ . Here are the genotypes of the first 1,000 progeny:

450  $AaBb$ , 450  $aabb$ , 50  $Aabb$ , and 50  $aaBb$ .  
(parental types)      (recombinant types)

**2** How far apart are the *a* and *b* genes?

What is the recombinant frequency? Which are the recombinant types, and which are the parental types?

Recombinant frequency (*a* to *b*) =  $(50 + 50)/1,000 = 0.1$

So the map distance is

Map distance =  $100 \times \text{recombinant frequency} =$   
 $100 \times 0.1 = 10 \text{ cM}$



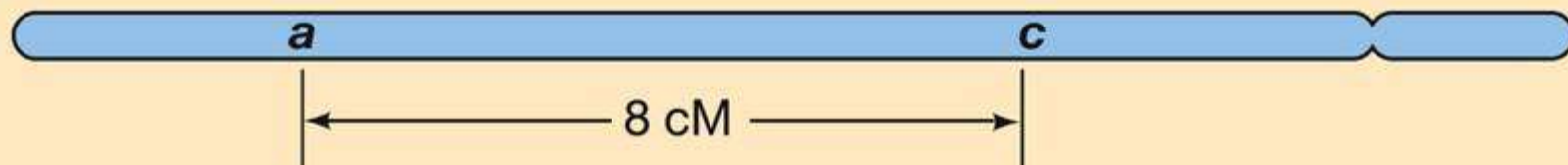
**3** How far apart are the *a* and *c* genes?

Now we make a cross  $AACC \times aacc$ , obtain an  $F_1$  generation, and test cross it, obtaining

460  $AaCc$ , 460  $aacc$ , 40  $Aacc$ , and 40  $aaCc$

Recombinant frequency (*a* to *c*) =  $(40 + 40)/1,000 = 0.08$

Map distance =  $100 \times \text{recombinant frequency} =$   
 $100 \times 0.08 = 8 \text{ cM}$



**4** How far apart are the *b* and *c* genes?

We make a cross  $BBCC \times bbcc$ , obtain an  $F_1$  generation, and test cross it, obtaining

490  $BbCc$ , 490  $bbcc$ , 10  $Bbcc$ , and 10  $bbCc$

Recombinant frequency (*b* to *c*) =  $(10 + 10)/1,000 = 0.02$

Map distance =  $100 \times \text{recombinant frequency} =$   
 $100 \times 0.02 = 2 \text{ cM}$

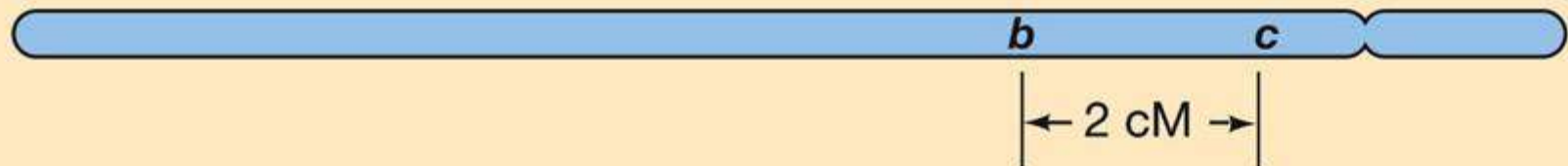
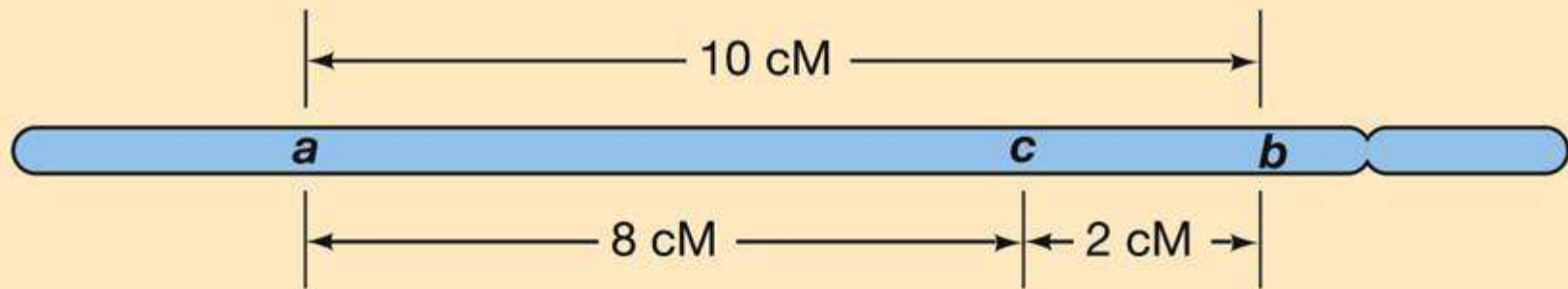




Figure 10.22 Map These Genes (Part 5)

- 5** Which of the three genes is between the other two?  
Because *a* and *b* are the farthest apart, *c* must be between them.



These numbers add up perfectly. In most real cases, they will not add up perfectly because of multiple crossovers.

## 10.4 What Is the Relationship between Genes and Chromosomes?

Sex determination varies among species.

Corn: each adult produces both male and female gametes—*monoecious* (“one house”).

Some plants and most animals are *dioecious* (“two houses”)—male and female gametes produced by different individuals.

## 10.4 What Is the Relationship between Genes and Chromosomes?

In most dioecious organisms, sex is determined by differences in the chromosomes.

Many animals have a pair of **sex chromosomes**; all others are **autosomes**.

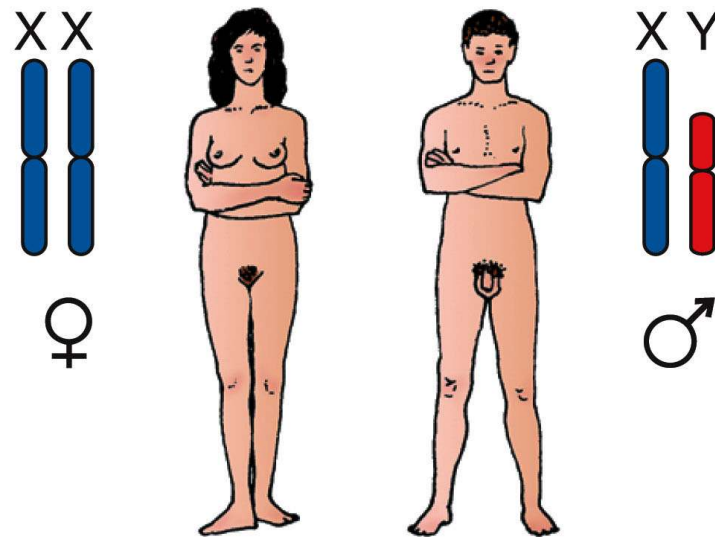


## 10.4 What Is the Relationship between Genes and Chromosomes?

Mammals:

Female has two X chromosomes.

Male has one X and one Y.

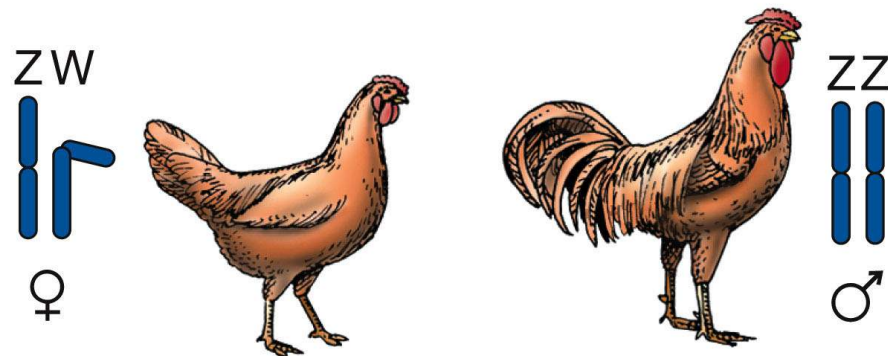


## 10.4 What Is the Relationship between Genes and Chromosomes?

Birds:

Females have one Z and one W.

Males have two Z chromosomes.



## 10.4 What Is the Relationship between Genes and Chromosomes?

Nondisjunction in meiosis:

Pair of sister chromosomes fail to separate in meiosis I, or

Pair of sister chromatids fail to separate in meiosis II.

Result is aneuploidy.

## 10.4 What Is the Relationship between Genes and Chromosomes?

If there is nondisjunction of sex chromosomes, possible outcomes:

XO—the individual has only one sex chromosome—*Turner syndrome*.

XXY—*Klinefelter syndrome*.

## 10.4 What Is the Relationship between Genes and Chromosomes?

The *SRY* gene—(sex-determining region on the Y chromosome) encodes a protein involved in primary sex determination.

If SRY protein is present, the embryo develops testes.

If there is no SRY, the embryo develops ovaries.

## 10.4 What Is the Relationship between Genes and Chromosomes?

A gene on the X chromosome, *DAX1*, produces an anti-testis factor.

SRY in males inhibits the *DAX1* maleness inhibitor.

## 10.4 What Is the Relationship between Genes and Chromosomes?

**Secondary sex determination** results in outward characteristics of each sex—not determined directly by presence or absence of Y chromosome.

Determined by genes scattered on all the chromosomes that control hormones.

## 10.4 What Is the Relationship between Genes and Chromosomes?

Genes on sex chromosomes don't follow Mendelian patterns.

The Y chromosome carries few genes; the X carries many.

Thus, males have only one copy of these genes—**hemizygous**.



## 10.4 What Is the Relationship between Genes and Chromosomes?

**Sex-linked inheritance**—governed by loci on the sex chromosomes.

Example: eye color in *Drosophila*

Figure 10.23 Eye Color Is a Sex-Linked Trait in *Drosophila* (Part 1)

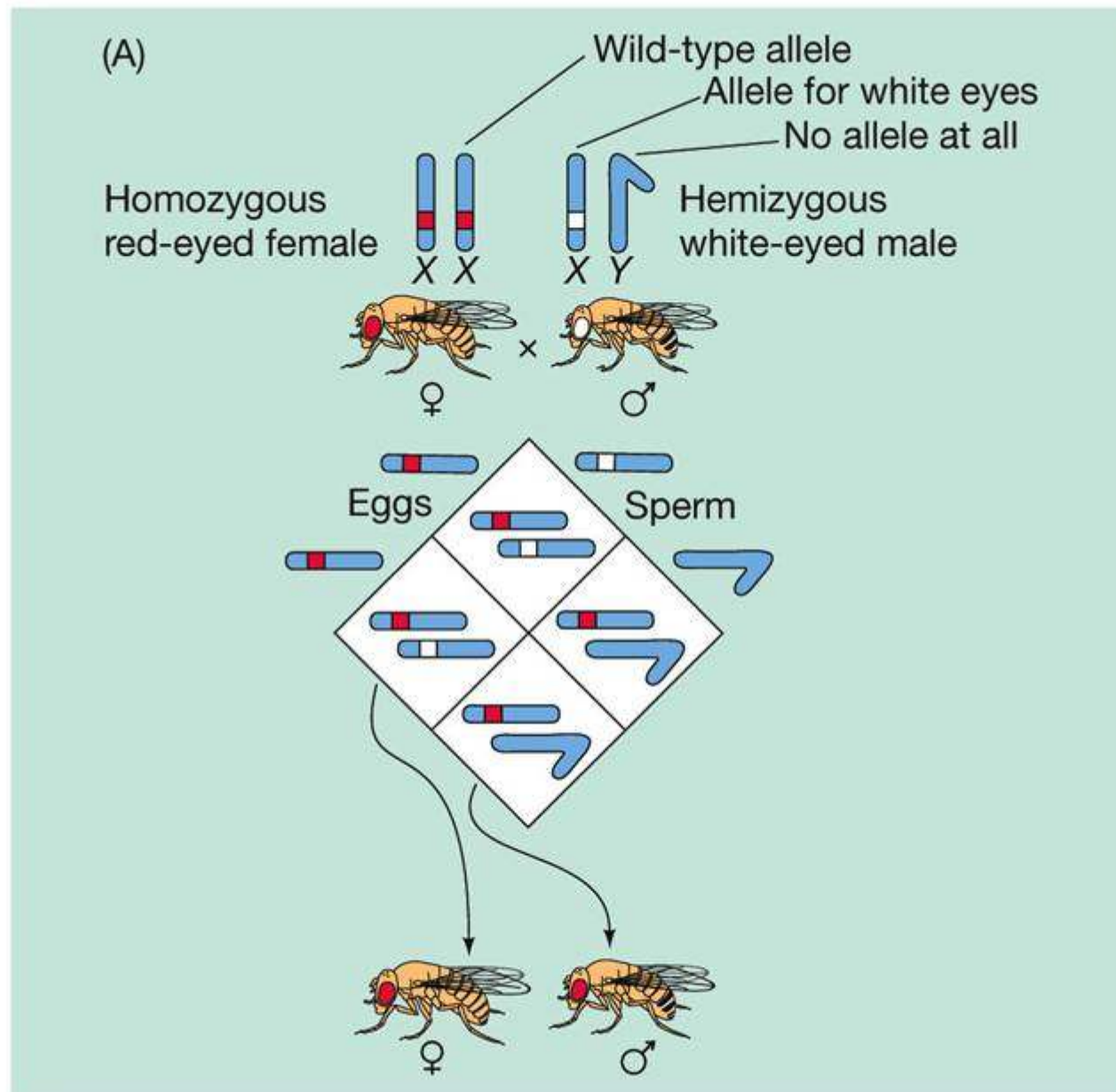
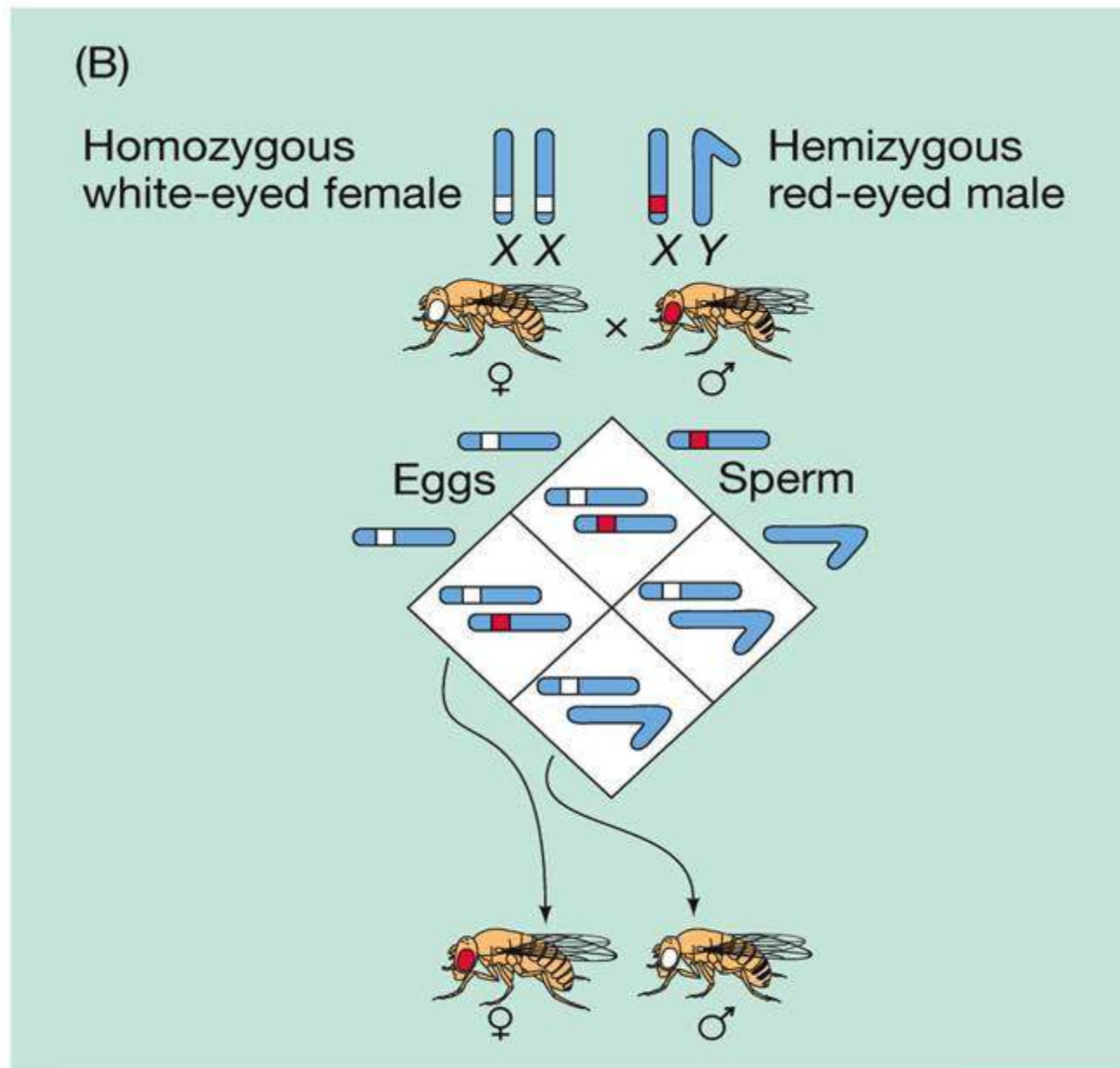


Figure 10.23 Eye Color Is a Sex-Linked Trait in *Drosophila* (Part 2)



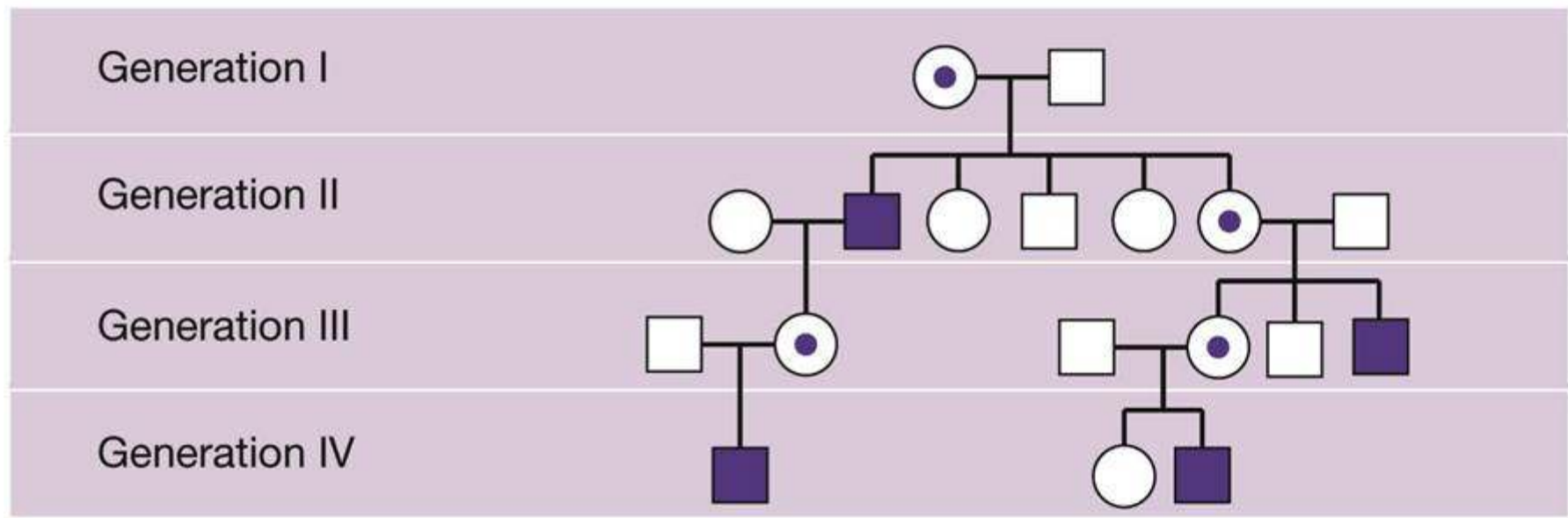
## 10.4 What Is the Relationship between Genes and Chromosomes?

### X-linked recessive phenotypes:

- Appear much more often in males than females
- Daughters who are heterozygous are **carriers**
- Mutant phenotype can skip a generation if it passes from a male to his daughter

Figure 10.24 Red-Green Color Blindness Is a Sex-Linked Trait in Humans

- Female who carries gene for phenotype of interest on one X chromosome



## 10.5 What Are the Effects of Genes Outside the Nucleus?

Mitochondria and plastids contain small numbers of genes—important in organelle assembly and function.

Mitochondria and plastids are inherited from the mother.

There may be hundreds of mitochondria or plastids in a cell.

## 10.5 What Are the Effects of Genes Outside the Nucleus?

Organelle genes tend to mutate faster than nuclear genes—multiple alleles.

Some plastid gene mutations affect chlorophyll synthesis, resulting in a white phenotype.

Mitochondria gene mutations may affect ATP production, especially in tissues with high energy requirements.