11.4 Meiosis

THINK ABOUT IT As geneticists in the early 1900s applied Mendel's principles, they wondered where genes might be located. They expected genes to be carried on structures inside the cell, but *which* structures? What cellular processes could account for segregation and independent assortment, as Mendel had described?

Chromosome Number

How many sets of genes are found in most adult organisms?

To hold true, Mendel's principles require at least two events to occur. First, an organism with two parents must inherit a single copy of every gene from each parent. Second, when that organism produces gametes, those two sets of genes must be separated so that each gamete contains just one set of genes. As it turns out, chromosomes—those strands of DNA and protein inside the cell nucleus—are the carriers of genes. The genes are located in specific positions on chromosomes.

Diploid Cells Consider the fruit fly that Morgan used, *Drosophila.* A body cell in an adult fruit fly has eight chromosomes, as shown in **Figure 11–14.** Four of the chromosomes come from its male parent, and four come from its female parent. These two sets of chromosomes are **homologous** (hoh MAHL uh gus), meaning that each of the four chromosomes from the male parent has a corresponding chromosome from the female parent. A cell that contains both sets of homologous chromosomes is said to be **diploid,** meaning "two sets." **The diploid cells of most adult organisms contain two complete sets of inherited chromosomes and two complete sets of genes.** The diploid number of chromosomes is sometimes represented by the symbol 2N. Thus, for *Drosophila,* the diploid number is 8, which can be written as $2N = 8$, where N represents the single set of chromosomes found in a sperm or egg cell.

Haploid Cells Some cells contain only a single set of chromosomes, and therefore a single set of genes. Such cells are **haploid,** meaning "one set." The gametes of sexually reproducing organisms, including fruit flies and peas, are haploid. For *Drosophila* gametes, the haploid number is 4, which can be written as $N = 4$.

Key Questions

How many sets of genes are found in most adult organisms?

What events occur during each phase of meiosis?

How is meiosis different from mitosis?

How can two alleles from different genes be inherited together?

Vocabulary

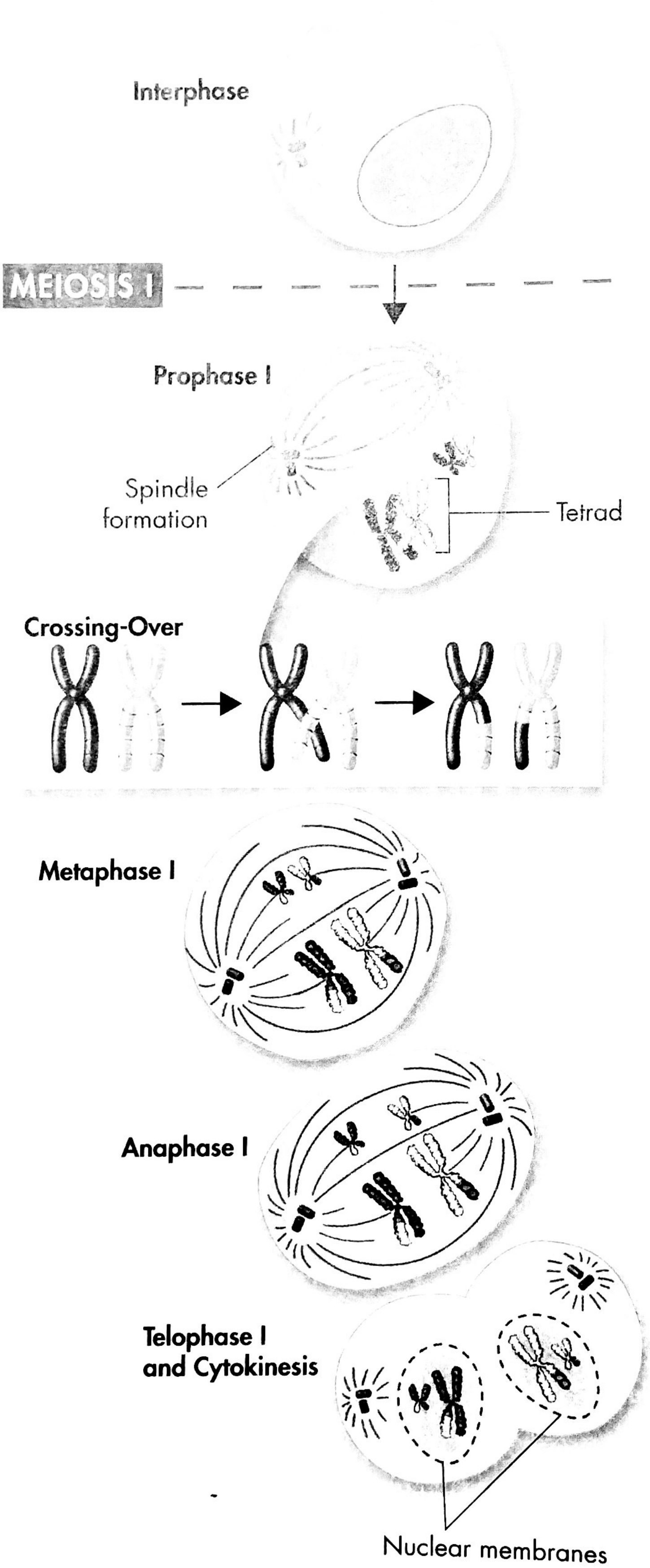
homologous • diploid • haploid • meiosis • tetrad • crossing-over • zygote

Taking Notes

Compare/Contrast Table Before you read, make a compare/contrast table to show the differences between mitosis and meiosis. As you read, complete the table.

FIGURE 11–14 Fruit Fly Chromosomes These chromosomes are from a fruit fly. Each of the fruit fly's body cells is diploid, containing eight chromosomes.

FIGURE 11–15 Meiosis I During meiosis I, a diploid cell undergoes a series of events that results in the production of two daughter cells. Neither daughter cell has the same sets of chromosomes that the original diploid cell had. Interpret Graphics *How does crossing-over affect the alleles on a chromosome?*



Phases of Meiosis

What events occur during each phases of meiosis?

How are haploid (N) gamete cells produced from diploid (2N) cells? That's where meiosis (my OH sis) comes in. **Meiosis** is a process in which the number of chromosomes per cell is cut in half through the separation of homologous chromosomes in a diploid cell. Meiosis usually involves two distinct divisions, called meiosis I and meiosis II. By the end of meiosis II, the diploid cell becomes four haploid cells. Let's see how meiosis takes place in a cell that has a diploid number of 4 (2N = 4).

Meiosis I Just prior to meiosis I, the cell undergoes a round of chromosome replication during interphase. As in mitosis, which was discussed in Chapter 10, each replicated chromosome consists of two identical chromatids joined at the center. Follow the sequence in **Figure 11–15** as you read about meiosis I.

▶ ***Prophase I*** After interphase I, the cell begins to divide, and the chromosomes pair up. **In prophase I of meiosis, each replicated chromosome pairs with its corresponding homologous chromosome.** This pairing forms a structure called a **tetrad,** which contains four chromatids. As the homologous chromosomes form tetrads, they undergo a process called **crossing-over.** First, the chromatids of the homologous chromosomes cross over one another. Then, the crossed sections of the chromatids—which contain alleles—are exchanged. Crossing-over therefore produces new combinations of alleles in the cell.

▶ ***Metaphase I and Anaphase I*** As prophase I ends, a spindle forms and attaches to each tetrad. **During metaphase I of meiosis, paired homologous chromosomes line up across the center of the cell.** As the cell moves into anaphase I, the homologous pairs of chromosomes separate. **During anaphase I, spindle fibers pull each homologous chromosome pair toward opposite ends of the cell.**

▶ ***Telophase I and Cytokinesis*** When anaphase I is complete, the separated chromosomes cluster at opposite ends of the cell. **The next phase is telophase I, in which a nuclear membrane forms around each cluster of chromosomes. Cytokinesis follows telophase I, forming two new cells.**

Meiosis I results in two cells, called daughter cells. However, because each pair of homologous chromosomes was separated, neither daughter cell has the two complete sets of chromosomes that it would have in a diploid cell. Those two sets have been shuffled and sorted almost like a deck of cards. The two cells produced by meiosis I have sets of chromosomes and alleles that are different from each other and from the diploid cell that entered meiosis I.

Meiosis II The two cells now enter a second meiotic division. Unlike the first division, neither cell goes through a round of chromosome replication before entering meiosis II.

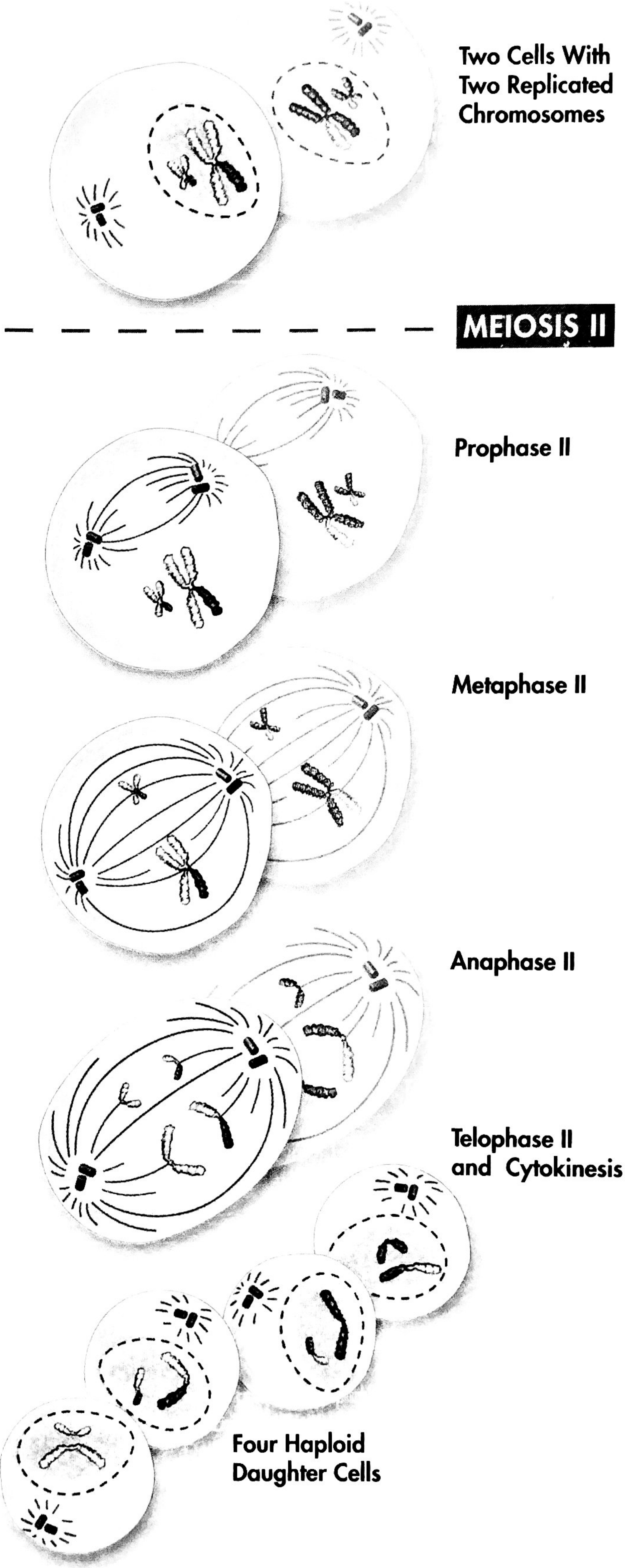
▶ ***Prophase II*** **As the cells enter prophase II, their chromosomes—each consisting of two chromatids—become visible.** The chromosomes do not pair to form tetrads, because the homologous pairs were already separated during meiosis I.

▶ ***Metaphase II, Anaphase II, Telophase II, and Cytokinesis*** During metaphase of meiosis II, chromosomes line up in the center of each cell. As the cell enters anaphase, the paired chromatids separate. **The final four phases of meiosis II are similar to those in meiosis I. However, the result is four haploid daughter cells.** In the example shown here, each of the four daughter cells produced in meiosis II receive two chromosomes. These four daughter cells now contain the haploid number (N)—just two chromosomes each.

Gametes to Zygotes The haploid cells produced by meiosis II are the gametes that are so important to heredity. In male animals, these gametes are called sperm. In some plants, pollen grains contain haploid sperm cells. In female animals, generally only one of the cells produced by meiosis is involved in reproduction. The female gamete is called an egg in animals and an egg cell in some plants. After it is fertilized, the egg is called a **zygote** (ZY goht). The zygote undergoes cell division by mitosis and eventually forms a new organism.

In Your Notebook *Describe the difference between meiosis I and meiosis II. How are the end results different?*

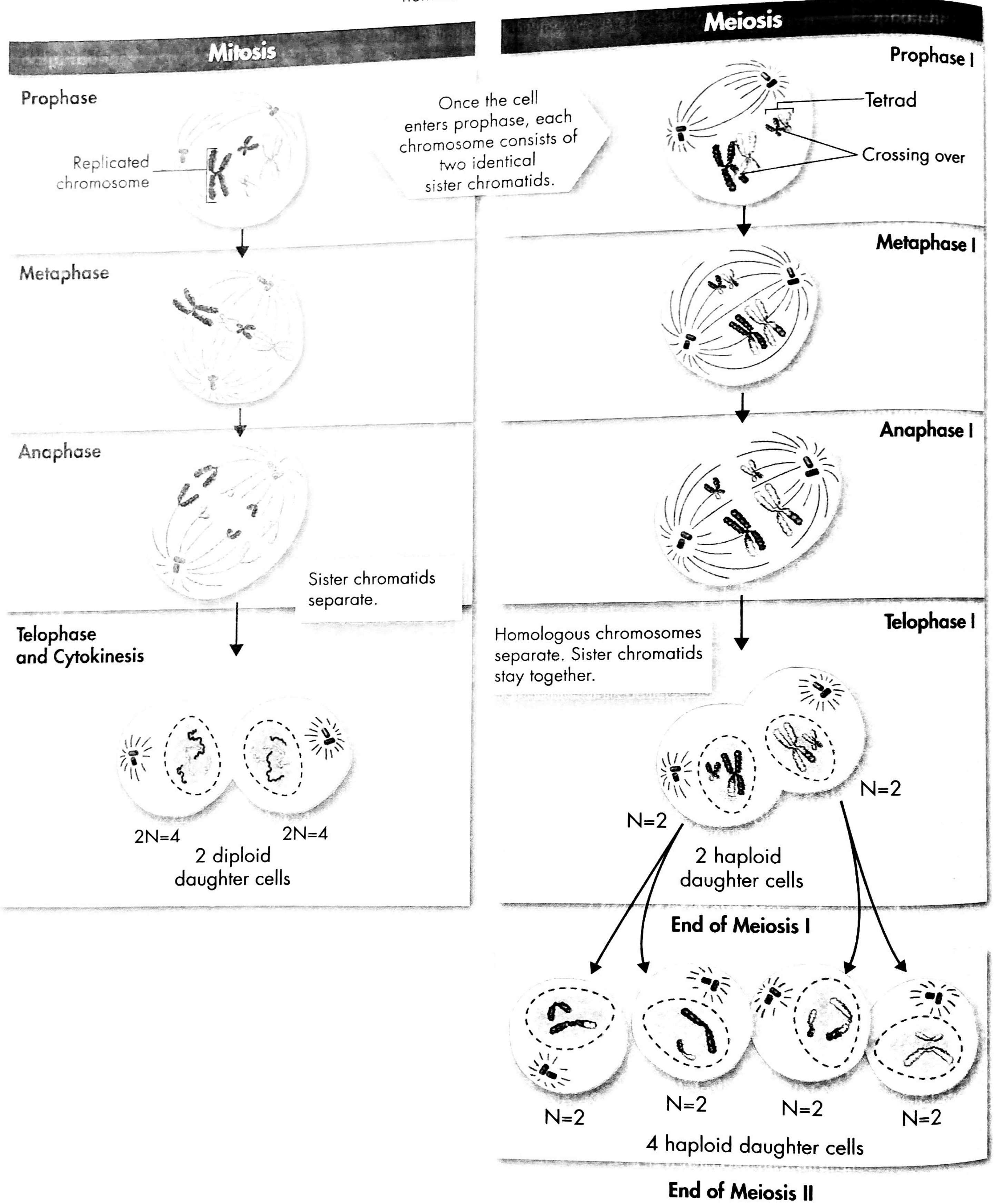
FIGURE 11–16 Meiosis II The second meiotic division, called meiosis II, produces four haploid daughter cells.



VISUAL SUMMARY

COMPARING MITOSIS AND MEIOSIS

FIGURE 11–17 Mitosis and meiosis both ensure that cells inherit genetic information. Both processes begin after interphase, when chromosome replication occurs. However, the two processes differ in the separation of chromosomes, the number of cells produced, and the number of chromosomes each cell contains.



Comparing Meiosis and Mitosis

How is meiosis different from mitosis?

The words *mitosis* and *meiosis* may sound similar, but the two processes are very different, as you can see in **Figure 11–17.** Mitosis can be a form of asexual reproduction, whereas meiosis is an early step in sexual reproduction. There are three other ways in which these two processes differ.

Replication and Separation of Genetic Material Mitosis and meiosis are both preceded by a complete copying, or replication, of the genetic material of chromosomes. However, the next steps differ dramatically. **In mitosis, when the two sets of genetic material separate, each daughter cell receives one complete set of chromosomes. In meiosis, homologous chromosomes line up and then move to separate daughter cells.** As a result, the two alleles for each gene are segregated, and end up in different cells. The sorting and recombination of genes in meiosis result in a greater variety of possible gene combinations than could result from mitosis.

Changes in Chromosome Number **Mitosis does not normally change the chromosome number of the original cell. This is not the case for meiosis, which reduces the chromosome number by half.** A diploid cell that enters mitosis with eight chromosomes will divide to produce two diploid daughter cells, each of which also has eight chromosomes. On the other hand, a diploid cell that enters meiosis with eight chromosomes will pass through two meiotic divisions to produce four haploid gamete cells, each with only four chromosomes.

Analyzing Data

Calculating Haploid and Diploid Numbers

Haploid and diploid numbers are designated by the algebraic notations N and 2N, respectively. Either number can be calculated when the other is known. For example, if the haploid number (N) is 3, the diploid number (2N) is 2×3, or 6. If the diploid number (2N) is 12, the haploid number (N) is 12/2, or 6.

The table shows haploid or diploid numbers of a variety of organisms. Copy the table into your notebook and complete it. Then, use the table to answer the questions that follow.

Trait Survey

Organism	Haploid Number	Diploid Number
Amoeba	N=25	
Chimpanzee	N=24	
Earthworm	N=18	
Fern		2N=1010
Hamster	N=22	
Human		2N=46
Onion		2N=16

1. **Calculate** What are the haploid numbers for the fern and onion plants? **MATH**
2. **Interpret Data** In the table, which organisms' diploid numbers are closest to that of a human?
3. **Apply Concepts** Why is a diploid number always even?
4. **Evaluate** Which organism's haploid and diploid numbers do you find the most surprising? Why?

Number of Cell Divisions Mitosis is a single cell division, resulting in the production of two identical daughter cells. On the other hand, meiosis requires two rounds of cell division, and, in most organisms, produces a total of four daughter cells. **Mitosis results in the production of two genetically identical diploid cells, whereas meiosis produces four genetically different haploid cells.**

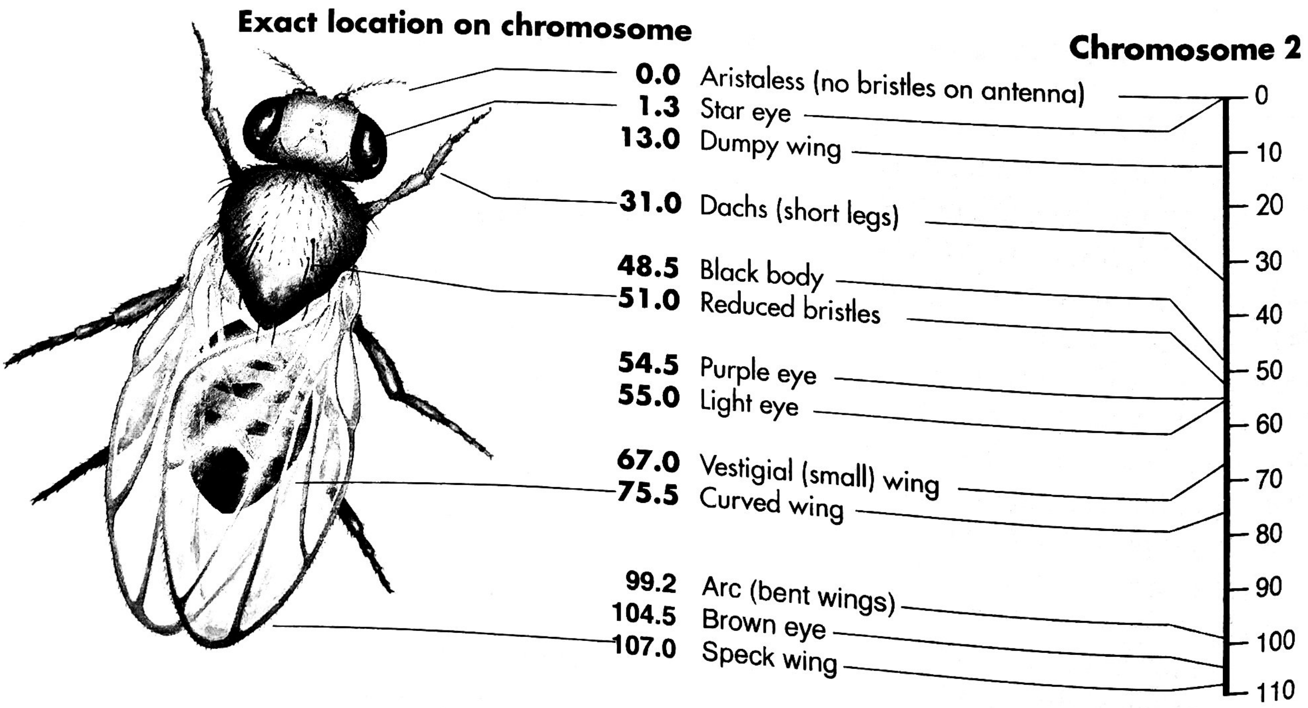
Gene Linkage and Gene Maps

How can two alleles from different genes be inherited together?

If you think carefully about Mendel's principle of independent assortment in relation to meiosis, one question might bother you. Genes that are located on different chromosomes assort independently, but what about genes that are located on the same chromosome? Wouldn't they generally be inherited together?

Gene Linkage The answer to this question, as Thomas Hunt Morgan first realized in 1910, is yes. Morgan's research on fruit flies led him to the principle of gene linkage. After identifying more than 50 *Drosophila* genes, Morgan discovered that many of them appeared to be "linked" together in ways that, at first glance, seemed to violate the principle of independent assortment. For example, Morgan used a fly with reddish-orange eyes and miniature wings in a series of test crosses. His results showed that the genes for those two traits were almost always inherited together. Only rarely did the genes separate from each other. Morgan and his associates observed so many genes that were inherited together that, before long, they could group all of the fly's genes into four linkage groups. The linkage groups assorted independently, but all of the genes in one group were inherited together. As it turns out, *Drosophila* has four linkage groups and four pairs of chromosomes.

FIGURE 11–18 Gene Map This gene map shows the location of a variety of genes on chromosome 2 of the fruit fly. The genes are named after the problems that abnormal alleles cause, *not* after the normal structures. **Interpret Graphics** ***Where on the chromosome is the "purple eye" gene located?***



Morgan's findings led to two remarkable conclusions. First, each chromosome is actually a group of linked genes. Second, Mendel's principle of independent assortment still holds true. It is the chromosomes, however, that assort independently, not individual genes. **Alleles of different genes tend to be inherited together from one generation to the next when those genes are located on the same chromosome.**

How did Mendel manage to miss gene linkage? By luck, or design, several of the genes he studied are on different chromosomes. Others are so far apart that they also assort independently.

Gene Mapping In 1911, a Columbia University student was working part time in Morgan's lab. This student, Alfred Sturtevant, wondered if the frequency of crossing-over between genes during meiosis might be a clue to the genes' locations. Sturtevant reasoned that the farther apart two genes were on a chromosome, the more likely it would be that crossing-over would occur between them. If two genes are close together, then crossovers between them should be rare. If two genes are far apart, then crossovers between them should be more common. By this reasoning, he could use the frequency of crossing-over between genes to determine their distances from each other.

Sturtevant gathered up several notebooks of lab data and took them back to his room. The next morning, he presented Morgan with a gene map showing the relative locations of each known gene on one of the *Drosophila* chromosomes. Sturtevant's method has been used to construct gene maps, like the one in **Figure 11–18,** ever since this discovery.

MYSTERY CLUE

White is the least common color found in parakeets. What does this fact suggest about the genotypes of both green parents?

11.4 Assessment

Review Key Concepts

1. a. Review Describe the main results of meiosis.

b. Calculate In human cells, 2N = 46. How many chromosomes would you expect to find in a sperm cell? How many would you expect to find in an egg cell? MATH

2. a. Review Write a summary of each phase of meiosis.

b. Use Analogies Compare the chromosomes of a diploid cell to a collection of shoes in a closet. How are they similar? What would make the shoe collection comparable to the chromosomes of a haploid cell?

3. a. Review What are the principal differences between mitosis and meiosis?

b. Apply Concepts Is there any difference between sister chromatids and homologous pairs of chromosomes? Explain.

4. a. Review How does the principle of independent assortment apply to chromosomes?

b. Infer If two genes are on the same chromosome but usually assort independently, what does that tell you about how close together they are?

Apply the Big idea

Information and Heredity

5. In asexual reproduction, mitosis occurs but meiosis does not occur. Which type of reproduction—sexual or asexual—results in offspring with greater genetic variation? Explain your answer.