Meiosis

MAIN IDEA **Meiosis produces haploid gametes.**

Real-World Reading Link Look around your biology class. You might notice that the students in your class do not look the same. They might be different heights and have different eye color, hair color, and other features. This variety of characteristics is a result of two sex cells combining during sexual reproduction.

Chromosomes and Chromosome Number

Each student in your biology class has characteristics passed on to them by their parents. Each characteristic, such as hair color, height, or eye color, is called a trait. The instructions for each trait are located on chromosomes, which are found in the nucleus of cells. The DNA on chromosomes is arranged in segments called **genes** that control the production of proteins. Each chromosome consists of hundreds of genes, each gene playing an important role in determining the characteristics and functions of the cell.

Homologous chromosomes

Human body cells have 46 chromosomes. Each parent contributes 23 chromosomes, resulting in 23 pairs of chromosomes. The chromosomes that make up a pair, one chromosome from each parent, are called **homologous chromosomes.** As shown in **Figure 1,** homologous chromosomes in body cells have the same length and the same centromere position, and they carry genes that control the same inherited traits. For instance, the gene for earlobe type will be located at the same position on both homologous chromosomes. Although these genes each code for earlobe type, they might not code for the exact same type of earlobe.

Figure 1 ■ Homologous chromosomes carry genes for any given trait at the same location. The genes that code for earlobe type might not code for the exact same type of earlobe.

Haploid and diploid cells

In order to maintain the same chromosome number from generation to generation, an organism produces **gametes,** which are sex cells that have half the number of chromosomes. Although the number of chromosomes varies from one species to another, in humans each gamete contains 23 chromosomes. The symbol n can be used to represent the number of chromosomes in a gamete. A cell with n number of chromosomes is called a **haploid** cell. Haploid comes from the Greek word *haploos,* meaning *single.*

The process by which one haploid gamete combines with another haploid gamete is called **fertilization.** As a result of fertilization, the cell now will contain a total of $2n$ chromosomes—n chromosomes from the female parent plus n chromosomes from the male parent. A cell that contains $2n$ number of chromosomes is called a **diploid** cell.

Notice that n also describes the number of pairs of chromosomes in an organism. When two human gametes combine, 23 pairs of homologous chromosomes are formed.

Reading Preview

Essential Questions

How does the reduction in chromosome number occur during meiosis?

What are the stages of meiosis?

What is the importance of meiosis in providing genetic variation?

Review Vocabulary

chromosome: cellular structure that contains DNA

New Vocabulary

gene
homologous chromosome
gamete
haploid
fertilization
diploid
meiosis
crossing over

4.1.b 4.2.b

Meiosis I

Gametes are formed during a process called **meiosis,** which is a type of cell division that reduces the number of chromosomes; therefore, it is referred to as a reduction division. Meiosis occurs in the reproductive structures of organisms that reproduce sexually. While mitosis maintains the chromosome number, meiosis reduces the chromosome number by half through the separation of homologous chromosomes. A cell with 2*n* number of chromosomes will have gametes with *n* number of chromosomes after meiosis, as illustrated in **Figure 2.** Meiosis involves two consecutive cell divisions called meiosis I and meiosis II.

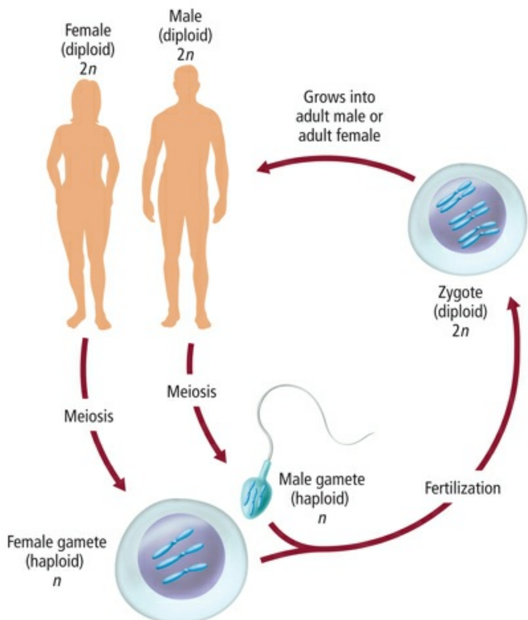


Figure 2 ■ The sexual life cycle in animals involves meiosis, which produces gametes. When gametes combine in fertilization, the number of chromosomes is restored.

Describe ***what happens to the number of chromosomes during meiosis.***

Interphase Recall that the cell cycle includes interphase prior to mitosis. Cells that undergo meiosis also go through interphase as part of the cell cycle. Cells in interphase carry out various metabolic processes, including the replication of DNA and the synthesis of proteins.

Prophase I As a cell enters prophase I, the replicated chromosomes become visible. As in mitosis, the replicated chromosomes consist of two sister chromatids. As the homologous chromosomes condense, they begin to form pairs in a process called synapsis. The homologous chromosomes are held tightly together along their lengths, as illustrated in **Figure 3.** Notice that in **Figure 4** the pink and green chromosomes have exchanged segments. This exchange occurs during synapsis. **Crossing over** is a process during which chromosomal segments are exchanged between a pair of homologous chromosomes.

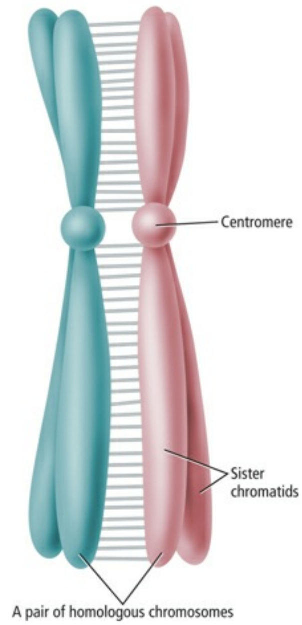


Figure 3 ■ The homologous chromosomes are physically bound together during synapsis in prophase I.

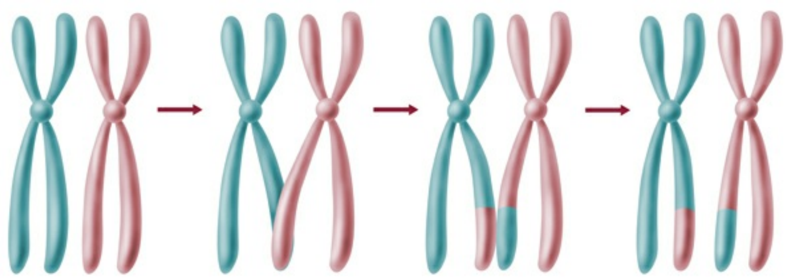


Figure 4 ■ The results of crossing over are new combinations of genes.

Determine ***which chromatids exchanged genetic material.***

As prophase I continues, centrioles move to the cell's opposite poles. Spindle fibers form and bind to the sister chromatids at the centromere.

Metaphase I In the next phase of meiosis, the pairs of homologous chromosomes line up at the equator of the cell, as illustrated in **Figure 5.** In meiosis, the spindle fibers attach to the centromere of each homologous chromosome. Recall that during metaphase in mitosis, the individual chromosomes, which consist of two sister chromatids, line up at the cell's equator. During metaphase I of meiosis, the homologous chromosomes line up as pairs at the cell's equator. This is an important distinction between mitosis and meiosis.

Anaphase I During anaphase I, the homologous chromosomes separate, which is also illustrated in **Figure 5.** Each member of the pair is guided by spindle fibers and moves toward opposite poles of the cell. The chromosome number is reduced from $2n$ to n when the homologous chromosomes separate. Recall that in mitosis, the sister chromatids split during anaphase. During anaphase I of meiosis, however, each homologous chromosome still consists of two sister chromatids.

Telophase I The homologous chromosomes, consisting of two sister chromatids, reach the cell's opposite poles. Each pole contains only one member of the original pair of homologous chromosomes. Notice in **Figure 5** that each chromosome still consists of two sister chromatids joined at the centromere. The sister chromatids might not be identical because crossing over might have occurred during synapsis in prophase I.

During telophase I, cytokinesis usually occurs, forming a furrow by pinching in animal cells and by forming a cell plate in plant cells. Following cytokinesis, the cells may go into interphase again before the second set of divisions. However, the DNA is not replicated again during this interphase. In some species, the chromosomes uncoil, the nuclear membrane reappears, and nuclei re-form during telophase I.

Visualizing Meiosis

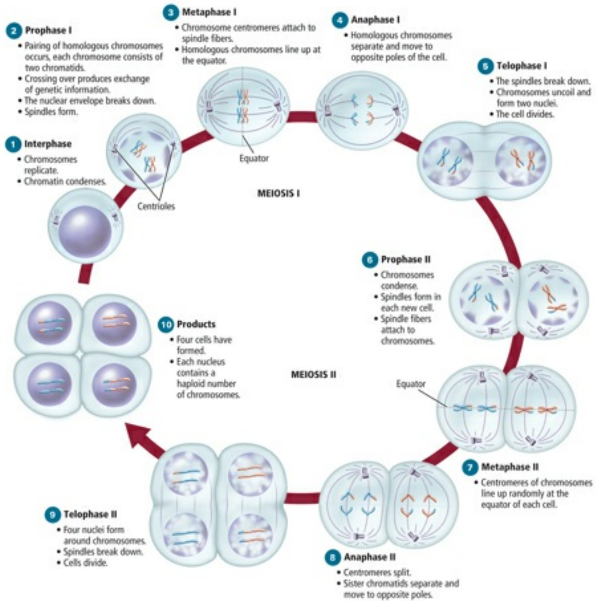


Figure 5 ■ Follow along the stages of meiosis I and meiosis II, beginning with interphase at the left.

4.1.b 4.2.b

Meiosis II

Meiosis is only halfway completed at the end of meiosis I. During prophase II, a second set of phases begins as the spindle apparatus forms and the chromosomes condense. During metaphase II, the chromosomes are positioned at the equator by the spindle fibers, as shown in **Figure 5.** During metaphase of mitosis, a diploid number of chromosomes line up at the equator. During metaphase II of meiosis, however, a haploid number of chromosomes line up at the equator. During anaphase II, the sister chromatids are pulled apart at the centromere by the spindle fibers, and the sister chromatids move toward the opposite poles of the cell. The chromosomes reach the poles during telophase II, and the nuclear membrane and nuclei reform. At the end of meiosis II, cytokinesis occurs, resulting in four haploid cells, each with *n* number of chromosomes, as illustrated in **Figure 5.**

Reading Check **Infer** Why are the two phases of meiosis important for gamete formation?

Careers in Biology

Medical Geneticist

A medical geneticist researches how diseases are inherited, how to diagnose genetic conditions, and treatments for genetic diseases.

2.2.b 1.e.(...)

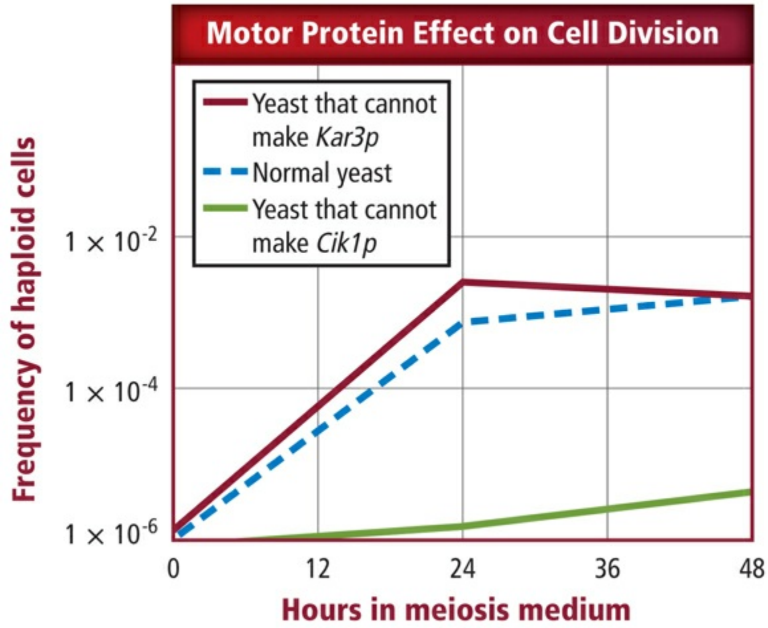
Data Analysis Lab

Based on Real Data*

Draw Conclusions

How do motor proteins affect cell division? Many scientists think that motor proteins play an important role in the movement of chromosomes in both mitosis and meiosis. To test this hypothesis, researchers have produced yeast that cannot make the motor protein called Kar3p. They also have produced yeast that cannot make the motor protein called Cik1p, which many think moderates the function of Kar3p. The results of their experiment are shown in the graph below.

Data and Observations



Think Critically

1. **Evaluate** whether Cik1p seems to be important for yeast meiosis. Explain.

2. **Assess** whether Kar3p seems to be necessary for yeast meiosis. Explain.

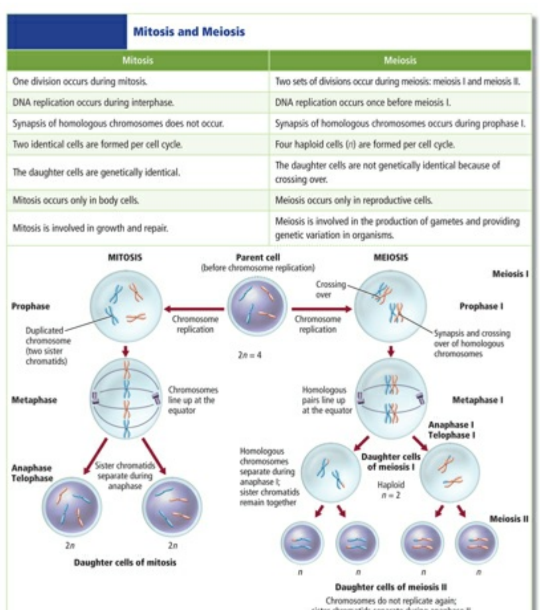
3. **Conclude** whether all motor proteins seem to play a vital role in meiosis. Explain.

*Data obtained from: Shanks, et al. 2001. The Kar3-Interacting protein Cik1p plays a critical role in passage through meiosis I in *Saccharomyces cerevisiae. Genetics* 159: 939-951.

4.1.b 4.2.b

The Importance of Meiosis

Table 1 shows a comparison of mitosis and meiosis. Recall that mitosis consists of only one set of division phases and produces two identical diploid daughter cells. Meiosis, however, consists of two sets of divisions and produces four haploid daughter cells that are not identical. Meiosis is important because it results in genetic variation.



Mitosis and Meiosis

Mitosis	Meiosis
One division occurs during mitosis.	Two sets of divisions occur during meiosis: meiosis I and meiosis II.
DNA replication occurs during interphase.	DNA replication occurs once before meiosis I.
Synapsis of homologous chromosomes does not occur.	Synapsis of homologous chromosomes occurs during prophase I.
Two identical cells are formed per cell cycle.	Four haploid cells (n) are formed per cell cycle.
The daughter cells are genetically identical.	The daughter cells are not genetically identical because of crossing over.
Mitosis occurs only in body cells.	Meiosis occurs only in reproductive cells.
Mitosis is involved in growth and repair.	Meiosis is involved in the production of gametes and providing genetic variation in organisms.

Table 1 Mitosis and Meiosis

Meiosis provides variation

Recall that pairs of homologous chromosomes line up at the equator during prophase I. How the chromosomes line up at the equator is a random process that results in gametes with different combinations of chromosomes, such as the ones in **Figure 6.** Depending on how the chromosomes line up at the equator, four gametes with four different combinations of chromosomes can result.

Notice that the first possibility shows which chromosomes were on the same side of the equator and therefore traveled together. Different combinations of chromosomes were lined up on the same side of the equator to produce the gametes in the second possibility. Genetic variation also is produced during crossing over and during fertilization, when gametes randomly combine.

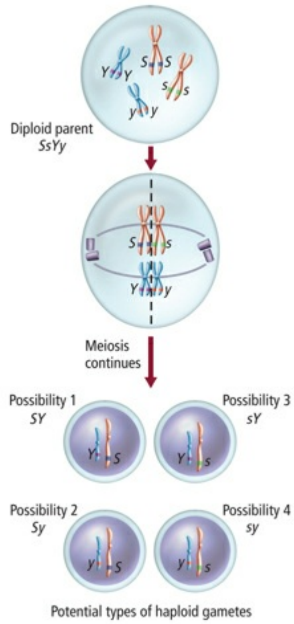


Figure 6 ■ The order in which the homologous pairs line up explains how a variety of sex cells can be produced.

4.1.b 4.2.b Sexual Reproduction v. Asexual Reproduction

Some organisms reproduce by asexual reproduction, while others reproduce by sexual reproduction. The life cycles of still other organisms might involve both asexual and sexual reproduction. During asexual reproduction, the organism inherits all of its chromosomes from a single parent. Therefore, the new individual is genetically identical to its parent. Bacteria reproduce asexually, whereas most protists reproduce both asexually and sexually, depending on environmental conditions. Most plants and many of the more simple animals can reproduce both asexually and sexually, compared to more advanced animals that reproduce only sexually.

Why do some species reproduce sexually while others reproduce asexually? Recent studies with fruit flies have shown that the rate of accumulation of beneficial mutations is faster when species reproduce sexually than when they reproduce asexually. In other words, when reproduction occurs sexually, the beneficial genes multiply faster over time than they do when reproduction is asexual.

Review

Lesson Summary

- DNA replication takes place only once during meiosis, and it results in four haploid gametes.
- Meiosis consists of two sets of divisions.
- Meiosis produces genetic variation in gametes.

Vocabulary Review

Use what you know about the terms in the lesson to answer the following questions.

1. When two cells with *n* number of chromosomes fuse, what type of cell results?

2. During which process are gametes formed?

3. What process results in an exchange of genes between homologous chromosomes?

Understand Main Ideas

4. MAIN IDEA **Analyze** how meiosis produces haploid gametes.

5. **Indicate** how metaphase I is different from metaphase in mitosis.

6. **Describe** how synapsis occurs.

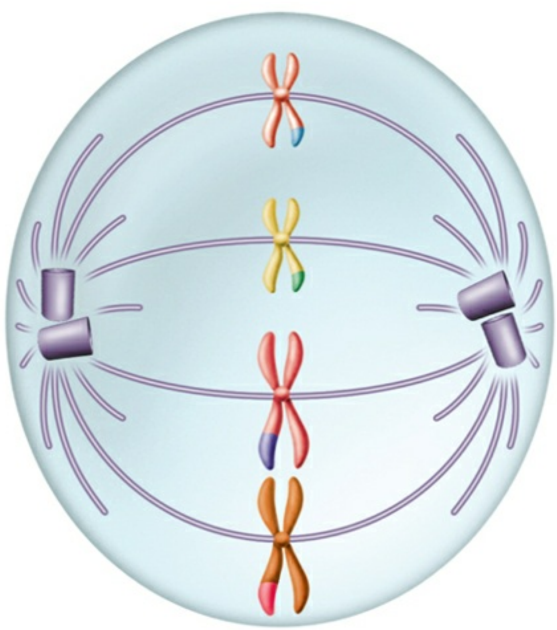
7. **Diagram** a cell with four chromosomes going through meiosis.

8. **Assess** how meiosis contributes to genetic variation, while mitosis does not.

9. How many chromosomes would a cell have during metaphase I of meiosis if it has 12 chromosomes during interphase?

A. 6
B. 12
C. 24
D. 36

Use the diagram below to answer questions 10 and 11.



10. Which stage of meiosis is illustrated above?

A. prophase I
B. prophase II
C. metaphase I
D. metaphase II

11. What is the next step for the chromosomes illustrated above?

A. They will experience replication.
B. They will experience fertilization.
C. Their number per cell will be halved.
D. They will divide into sister chromatids.

12. Which is not a characteristic of homologous chromosomes?

A. Homologous chromosomes have the same length.

B. Homologous chromosomes have the same centromere position.

C. Homologous chromosomes have the exact same type of allele at the same location.

D. Homologous chromosomes pair up during meiosis I.

Constructed Response

13. MAIN IDEA Relate the terms meiosis, gametes, and fertilization in one or two sentences.

14. **Open Ended** Plant cells do not have centrioles. Hypothesize why plant cells might not need centrioles for mitosis or meiosis.

Think Critically

15. **Compare and contrast** mitosis and meiosis, using **Figure 5** and **Table 1,** by creating a Venn diagram.

16. **Analyze** A horse has 64 chromosomes and a donkey has 62. Using your knowledge of meiosis, evaluate why a cross between a horse and a donkey produces a mule, which usually is sterile.

17. **Hypothesize** In bees, the female queen bee is diploid but male bees are haploid. The fertilized eggs develop into female bees and the unfertilized eggs develop into males. How might gamete production in male bees differ from normal meiosis?

WRITING in Biology

18. Imagine you are a chromosome going through meiosis. Describe what happens to you and the other chromosomes.