7.1

Meiosis

Sperm and egg cells are produced during the process of meiosis.

CAN YOU EXPLAIN IT?

FIGURE 1: Could it be possible that everyone has a twin?

Humans have unique versions of traits that cause us to look and act differently from one another. Aside from identical twins, there is great variety in physical traits from one person to the next. However, some people believe there may be an exact copy of themselves somewhere in the world. For example, some have claimed to have found their "twin" on the Internet. Have you ever wondered if there could be a copy of you somewhere else in the world? Do you think it is possible for someone to be born from a different mother and father, yet have the same genetic makeup as you?

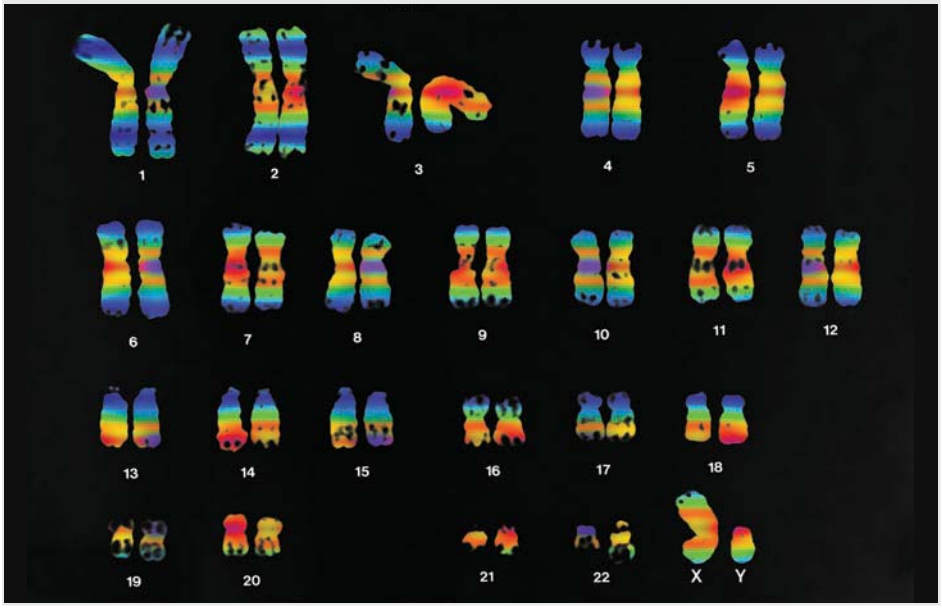
Predict What do you think the chances are that there is someone in the world exactly like you?

Gather Evidence
As you explore the lesson, gather evidence to explain how meiosis and sexual reproduction increase genetic diversity.

Chromosomes and Meiosis

DNA is the genetic material in organisms. DNA codes for proteins and contains the information that determines when proteins are made. In complex organisms, long strands of DNA are packaged together with proteins into chromosomes in the nucleus of the cell. Images like the one in Figure 2 can be analyzed to determine a karyotype, which shows the 23 pairs of chromosomes in a human cell. The brightly colored structures are pairs of highly condensed chromosomes formed during metaphase of mitosis.

FIGURE 2: Chromosomes in a Human Cell



Collaborate Write your answers to the following questions about the image in Figure 2. Compare your answers with a partner, and write down any new information that you had not previously recorded.

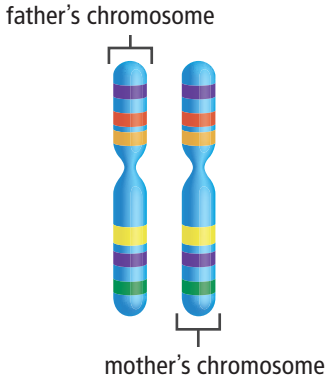
1. What patterns do you observe?
2. How many chromosomes do human body cells have?
3. What differences do you see among the different pairs of chromosomes and the chromosomes within a pair?

Chromosome Structure and Function

Each pair of chromosomes in your cells is referred to as a homologous pair. Homologous chromosomes are two chromosomes—one inherited from the mother, one from the father—that have the same length and general appearance. These chromosomes have copies of the same genes, although the two copies may differ.

Analyze What percentage of your genetic material is from your mother and what percentage is from your father?

FIGURE 3: Homologous chromosome pairs include one chromosome inherited from the father and another inherited from the mother.



Autosomes and Sex Chromosomes

You may have noticed that all of the chromosome sets in Figure 2 are labeled with a number except for one set, which is labeled with an X and a Y. Together, chromosome pairs 1 through 22 make up your autosomes, which are chromosomes that contain genes for characteristics not directly related to the sex of an organism.

Analyze Do the chromosomes in Figure 2 on the previous page belong to a female or a male? Explain how you know.

Most sexually reproducing species also have sex chromosomes that directly control the development of sexual characteristics. Humans have two very different sex chromosomes: X and Y. In most mammals, including humans, an organism's sex is primarily determined by the XY system. An organism with two X chromosomes, or XX, is female. An organism with one X and one Y chromosome, or XY, is male.

FIGURE 4: Sex chromosomes control the development of sexual characteristics.

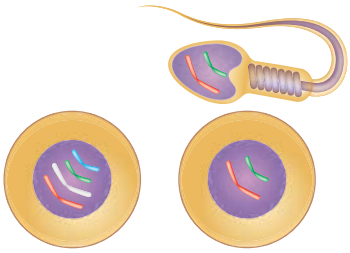
a Females have two X chromosomes.

b Males have an X chromosome and a Y chromosome.

Body Cells and Germ Cells

The 23 pairs of chromosomes you analyzed earlier are from a body, or somatic, cell. Your body cells are called diploid cells because they contain two copies of every chromosome. However, the two copies are not exact copies because one is from your mother and one is from your father. Diploid cells can be represented as 2*n*. In humans, the diploid chromosome number is 46.

FIGURE 5: Body Cells and Gametes (Cells are not to scale.)



Body cells are diploid (2*n*).

Gametes (sex cells) are haploid (*n*).

In addition to body cells, you also have germ cells located in your reproductive organs. Germ cells form gametes, or sex cells. The male sex cells are sperm and the female sex cells are eggs. Unlike body cells, gametes have only one copy of each chromosome. These cells are called haploid and can be represented as *n*. Human gametes thus contain 23 chromosomes. Only DNA in gametes is passed down to the organism's offspring. The DNA in body cells is not.

Sexual reproduction involves the fusion of two gametes of different types, resulting in offspring that are a genetic mixture of both parents. The joining of these two gametes is called fertilization. When fertilization occurs, the nuclei of the egg and sperm fuse to form a single nucleus.

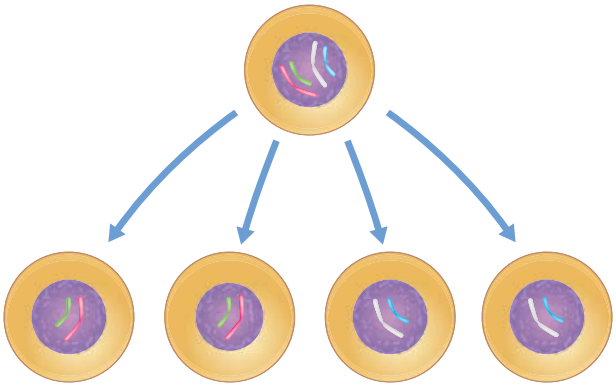
Explain Answer the following questions about body cells and gametes.

1. What is an example of a body cell in your body?
2. Why do gametes have half a set of DNA? What would happen if they had a full set of DNA? Explain your answer.

The Process of Meiosis

Recall that body cells reproduce during part of the cell cycle. During mitosis and cytokinesis, the nucleus and cytoplasm divide, resulting in daughter cells that are genetically identical to the parent cell. Germ cells in your reproductive organs undergo the process of meiosis to form gametes. Meiosis is a form of nuclear division that divides one diploid cell into four haploid cells. There are two rounds of cell division—meiosis I and meiosis II. This process divides the DNA and reduces each resulting cell's chromosome number by half.

FIGURE 6: Meiosis has many stages and produces four haploid cells from one diploid cell.



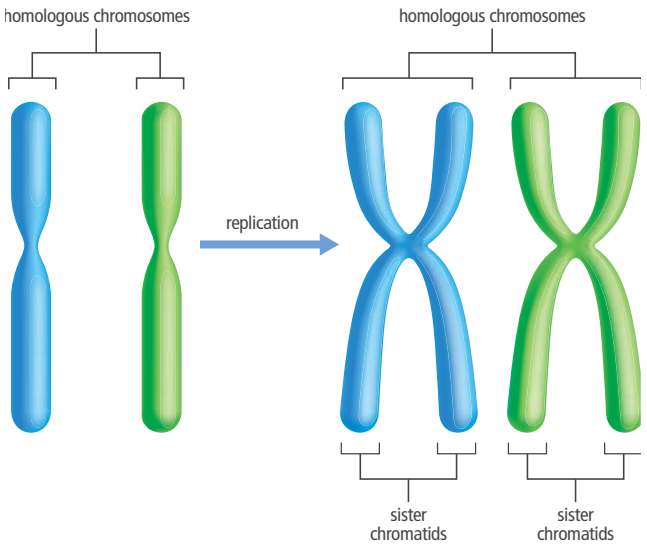
Predict Meiosis divides one cell into four cells, but each resulting cell has half the amount of DNA as compared to the original cell. How do you think this is possible?

Chromosomes and Replication

To understand meiosis, it is necessary to distinguish between homologous chromosomes and sister chromatids. As Figure 7 shows, homologous chromosomes are two separate chromosomes, one from your mother and one from your father. Homologous chromosomes are similar to each other because they are the same length and carry the same genes. However, they are not exact copies of each other. In contrast, a chromatid is one half of a duplicated chromosome. Sister chromatids refers to the duplicated chromosomes that remain attached (by the centromere). Homologous chromosomes divide during meiosis I, and sister chromatids are split and separated into new gametes during meiosis II.

Analyze What is the difference between the genetic material on two sister chromatids and the genetic material on homologous chromosomes?

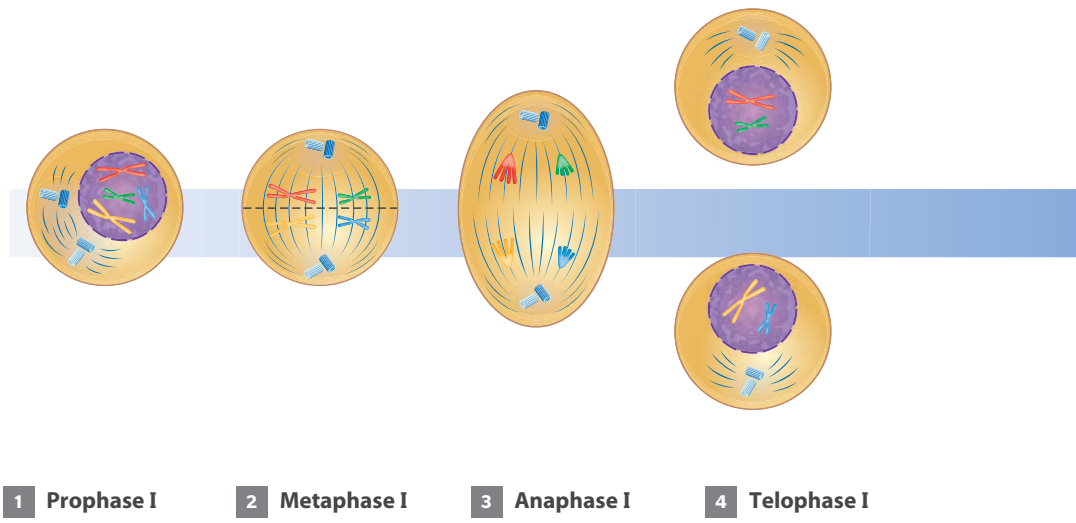
FIGURE 7: Homologous chromosomes are two separate chromosomes, while sister chromatids are duplicated chromosomes that remain attached to one another.



Meiosis I

Before meiosis begins, DNA is copied during S phase. Meiosis I separates homologous chromosomes, producing two haploid cells with duplicated chromosomes. Meiosis I can be described in distinct phases, each of which is a series of gradual changes.

FIGURE 8: Meiosis I and meiosis II are each made up of four phases.



Explore Online

Hands-On Lab

Modeling Meiosis

Make a model to illustrate how the arrangement and separation of chromosomes during meiosis causes an increase in genetic diversity.

1. Prophase I During this first phase of meiosis, the nuclear membrane breaks down, the centrosomes and centrioles move to opposite sides of the cell, and spindle fibers start to assemble. The duplicated chromosomes condense, and homologous chromosomes pair up. They appear to pair up precisely, gene for gene, down their entire length. The sex chromosomes also pair with each other, and some regions of their DNA appear to line up as well.

2. Metaphase I The homologous chromosome pairs randomly line up along the middle of the cell, or the cell equator, attached to spindle fibers. The result is that 23 chromosomes—some from the father, some from the mother—are lined up along each side of the cell equator. This arrangement mixes up the chromosomal combinations and helps make and maintain genetic diversity.

3. Anaphase I Next, the paired homologous chromosomes separate from each other and move toward opposite sides of the cell. The sister chromatids remain together during this step and throughout meiosis I.

4. Telophase I The cell undergoes cytokinesis.

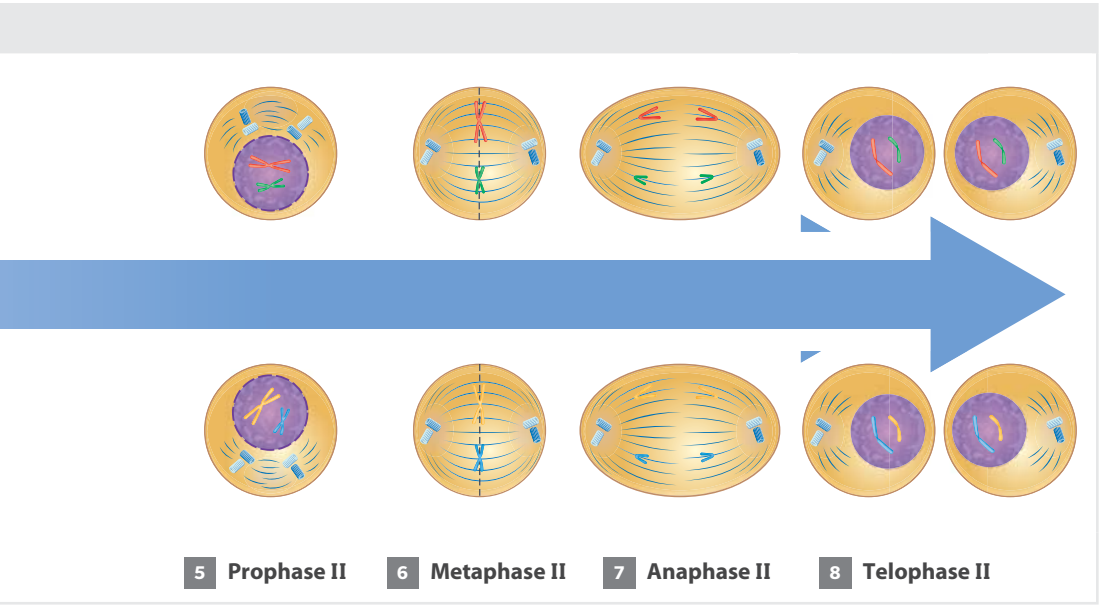
After telophase I, the nuclear membrane forms again in some species, and the spindle fibers disassemble. These steps occur during a period between meiosis I and meiosis II.

Analyze Observe the model of meiosis I in Figure 8. Use this model to answer the following questions:

1. What are the products of meiosis I? Explain in terms of number of cells and the genetic material contained in those cells.
2. Describe the arrangement of chromosomes in metaphase I. Why do you think chromosomes are arranged in this way?
3. What are some of the strengths and limitations of this model?

Meiosis II

Meiosis II separates sister chromatids, which results in chromosomes that are not doubled. The diagram of this process applies to both of the cells produced in meiosis I. It's important to note that DNA is not copied between meiosis I and meiosis II.



5. Prophase II The nuclear membrane breaks down, centrosomes and centrioles move to opposite sides of the cell, and spindle fibers assemble.

6. Metaphase II Spindle fibers align the 23 chromosomes at the cell equator. Each chromosome still has two sister chromatids at this stage.

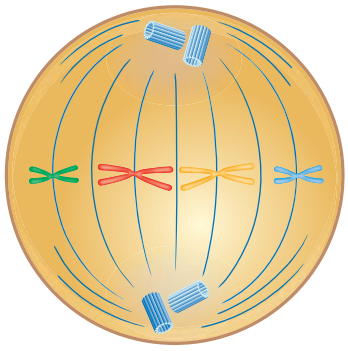
7. Anaphase II Next, the sister chromatids are pulled apart from each other and move to opposite sides of the cell.

8. Telophase II Finally, nuclear membranes form around each set of chromosomes at opposite ends of the cell, the spindle fibers break apart, and the cell undergoes cytokinesis.

Explain According to this model, do all the gametes produced by an organism have the same genetic material? Use evidence to support your claim.

Cause and Effect

FIGURE 9: Metaphase in Mitosis



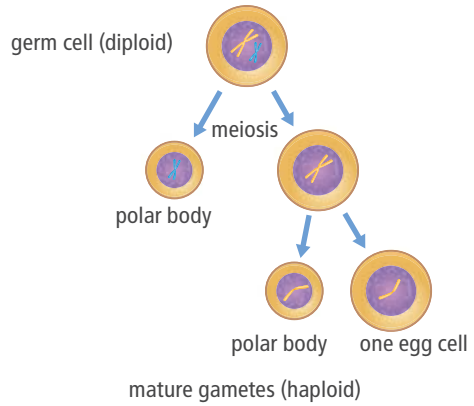
Comparing Chromosome Arrangement

Mitosis, which occurs in body cells, produces two genetically identical cells. Like meiosis, mitosis includes metaphase. However, the alignment of chromosomes differs, which affects the genetic makeup of the final cells.

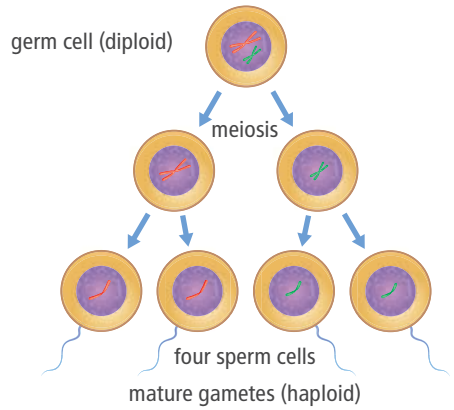
Explain Answer these questions about metaphase in meiosis and mitosis.

1. How do the arrangements of chromosomes in metaphase I and metaphase II of meiosis compare to each other and to the metaphase stage of mitosis?
2. What are the final products of mitosis and meiosis? How does the arrangement of chromosomes during metaphase affect the genetic makeup of the final products?

FIGURE 10: Gametogenesis (Cells are not to scale.)



a egg production



b sperm production

Gametogenesis

The haploid cells produced by meiosis are not able to be fertilized until they go through additional changes to produce mature gametes. The final stages of this process, called gametogenesis, differ between the sexes. The formation of an egg, the female gamete, begins before birth, inside the developing body of a female embryo, and is not finished until a sperm fertilizes that egg many years later. Only one of the four cells produced by meiosis actually makes an egg. The other cells produced are called polar bodies and are not typically able to be fertilized. Nearly all of a zygote's cytoplasm and organelles come from the egg. Since mitochondria carry their own DNA, the mitochondrial DNA in the embryo is identical to the mother's.

The sperm cell, the male gamete, is much smaller than the egg. The sperm cell's main contribution to an embryo is DNA. Yet it must swim to an egg to fertilize it, so the ability to move is critical. Sperm formation starts with a round cell and ends by making a streamlined cell that can move rapidly. During this process, significant changes occur. DNA is tightly packed and much of the cytoplasm is lost, resulting in a compact head. The sperm cell develops a whip-like flagellum and a neck region with mitochondria that provide the energy needed to drive the cell's flagellum. Other changes, such as the addition of proteins to the cell membrane, also take place.

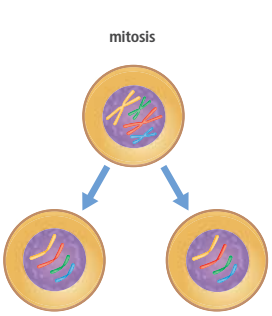
Analyze Make a Venn diagram to compare and contrast egg production and sperm production.

Comparing Mitosis and Meiosis

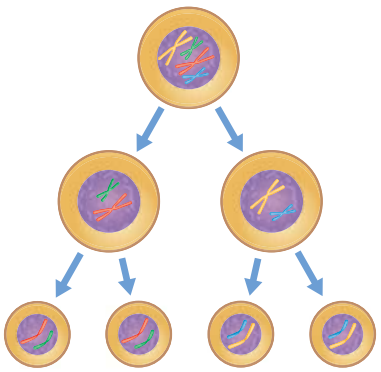
Mitosis is a process that occurs in body cells. It is essential for the growth and development of an organism. In contrast, meiosis occurs in germ cells.

Explain Make a table to compare mitosis and meiosis in terms of the number and type of cells produced, the genetic material in the cells, and the role of each process in the body. Does meiosis or mitosis occur more frequently in your body? Explain your answer.

FIGURE 11: Mitosis and meiosis produce different kinds of cells.



a Mitosis



b Meiosis

Meiosis and Genetic Variation

One of the major outcomes of meiosis and sexual reproduction is the resulting increased genetic diversity within a species. Genetic variation refers to differences in the genetic material of individuals in a population.

FIGURE 12: Genetic variation is responsible for the different versions of traits you see in this cat's offspring.

Mechanisms of Genetic Variation

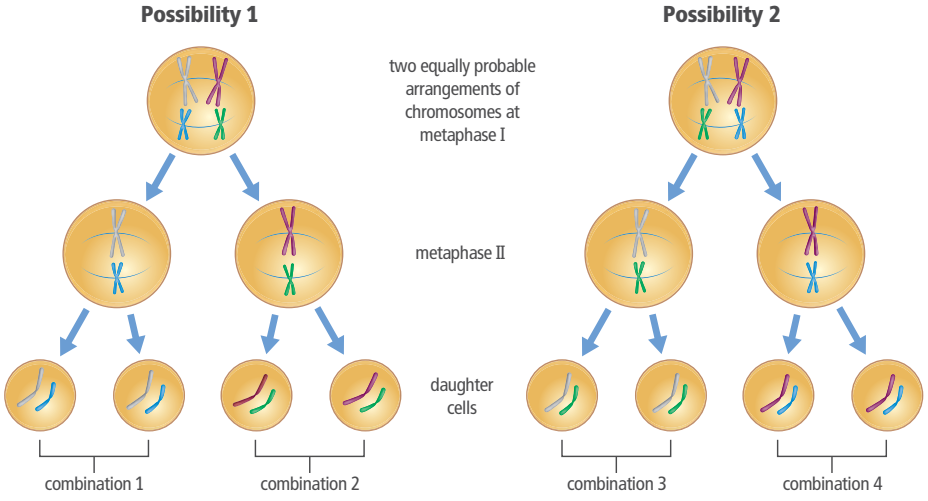
Meiosis and sexual reproduction increase genetic diversity, or genetic variation, within a population. Gametes have different combinations of genes than their parent cells due to crossing over and independent assortment, which both occur during meiosis.

Independent Assortment

When homologous chromosomes pair up in metaphase I of meiosis, the chromosomes from your father and the chromosomes from your mother line up randomly on either side of the cell's equator. This assortment of chromosomes is a matter of chance. The arrangement of any one homologous pair does not depend on the arrangement of any other homologous pair. Therefore, it is referred to as independent assortment.

FIGURE 13: Independent Assortment

Explore Online



Problem Solving

To determine the number of possible chromosome combinations that can result from independent assortment, you can use this formula:

$$\text{Combinations} = 2^n$$

where n = number of different chromosomes.

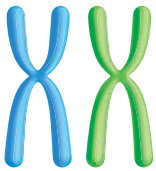
1. What is the number of possible chromosome combinations for a human cell with 23 different chromosomes?
2. How does your answer to Question 1 support the claim that independent assortment increases variation in an organism's offspring?

Crossing Over

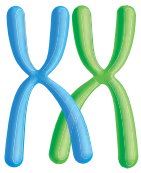
Crossing over is the exchange of chromosome segments between homologous chromosomes. It occurs during prophase I in meiosis I, and it is a regulated process. At this stage of meiosis, each chromosome has been duplicated, the sister chromatids are still connected, and homologous chromosomes have paired up. Some of the chromatids are very close to each other. Part of one chromatid from a chromosome may break off and reattach to the other chromosome. Because crossing over results in new combinations of genes, it is an example of genetic recombination.

FIGURE 14: Crossing Over

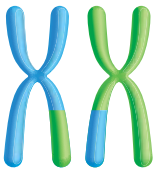
Explore Online



1 Two homologous chromosomes pair up with each other during prophase I in meiosis.



2 In this position, some chromatids are very close to each other and segments cross.



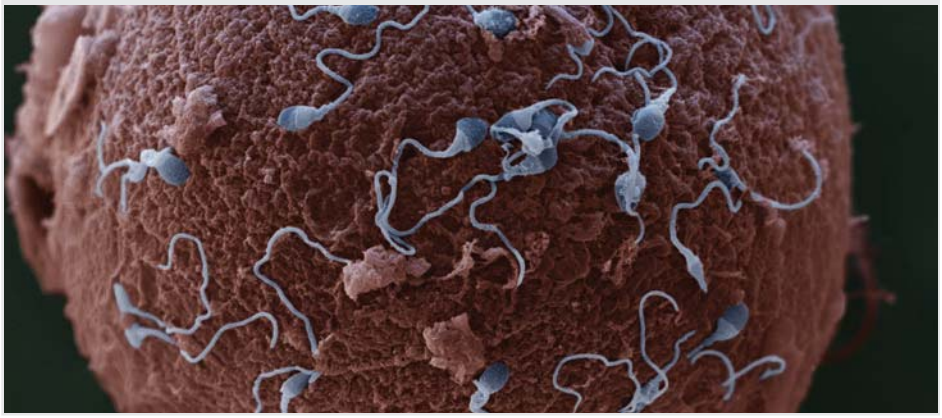
3 Some of these segments break off and reattach to the other homologous chromosome.

Explain How does crossing over contribute to genetic diversity?

Fertilization

Once mature gametes have formed during the process of gametogenesis, the gametes are ready for fertilization. In fertilization, two gametes of different types fuse, producing a zygote with a complete set of DNA—half from one parent and half from the other. The zygote formed will have a unique combination of genes. The mixing and matching of genetic material during meiosis and fertilization is responsible for the genetic variation in sexually reproducing organisms.

FIGURE 15: Fertilization results in a genetically unique organism.

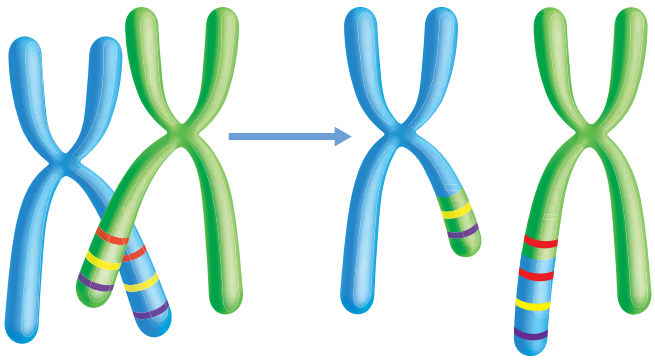


Explain Use what you have learned about meiosis and sexual reproduction to construct an explanation for why offspring are not exact replicas of their parents. In your answer, include a discussion of sexual reproduction, independent assortment, and crossing over.

Guided Research

Gene Duplication and Genetic Variation

FIGURE 16: Gene duplication has influenced the traits of domestic sunflower plants.



In metaphase I of meiosis, homologous chromosomes exchange DNA segments via crossing over. This leads to genetic variation in the offspring of sexually reproducing organisms. Sometimes during crossing over, homologous chromosomes do not align with each other properly. If this happens, the two segments crossing over may be different in size. As a result, one chromosome may have two copies of a gene or genes, which is called gene duplication. The other chromosome may have no copy of the gene or genes, known as a gene deletion.

Gene duplication has occurred many times over millions of years of eukaryotic evolution. For example, domesticated sunflowers have a duplicated gene that lengthens plants' growing period. Interestingly, this gene duplication is not the result of domestication. Evidence shows that the duplication occurred long before Native Americans began breeding the plants as a part of their horticultural practices. This variation of sunflower was simply preferred by Native Americans.

Language Arts Connection Conduct research to construct an argument for how gene duplication increases genetic variation. Start by choosing a specific species to research, and look for materials explaining how gene duplication has affected this species. As you conduct your research, evaluate your sources carefully to be sure they are reliable. Do they present verifiable facts? Are the opinions those of an expert or experts in this field? Is there enough evidence to support the claims being made?

Using your own words, write an argument explaining how gene duplication from unequal crossing over has influenced genetic variation in a certain species. Use these questions to guide your research:

1. Which species will you be researching, and what evidence exists that gene duplication has occurred in this species?
2. How did gene duplication influence the traits of this species?
3. What is the connection between gene duplication and the evolution of this species?

INVESTIGATING GENETIC LINKAGE | GATHERING EVIDENCE FOR GENETIC DIVERSITY | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 17: How likely is it that there is a genetic copy of you somewhere?

Now that you have learned about meiosis and genetic variation, think again about the possibility of finding a genetic copy of yourself. According to some estimates, the number of possible gene combinations made by meiosis is trillions of times more than the number of people who have ever lived on Earth. Independent assortment alone makes millions of possible combinations of chromosomes. Each chromosome contains anywhere from hundreds to thousands of genes. When those genes are shuffled during meiosis, an astounding number of combinations is possible. Multiply this by the probability that the gametes that formed you would merge, and it's no wonder there is so much variation in the human race.

Explain In general, how likely is it that there is someone in the world who is genetically identical to you? Refer to the notes in your Evidence Notebook to construct an explanation for this question using a claim, evidence, and reasoning. Your explanation should include a discussion of sexual reproduction, meiosis, crossing over, and independent assortment.

1. State your claim.
2. Cite evidence to support your claim. Include models and examples as necessary.
3. Explain how the evidence you cited supports your claim. For example, consider the number of possible chromosome combinations made by independent assortment. How would this evidence support the statement you are making?

CHECKPOINTS

Check Your Understanding

1. Fruit fly gametes each have four chromosomes representing 2^4, or 16, possible chromosome combinations. How many chromosome combinations could results from fertilization between a fruit fly egg and a sperm cell?

2. A student uses string to model four pairs of homologous chromosomes in a parent cell. Each chromosome pair is a different color. Which model would best show the genetic makeup of a daughter cell produced by meiosis?

a. two strings, each a combination of different colors

b. two strings, each the same color

c. four strings, each a combination of different colors

d. four strings, each the same color

3. Which of the following statements describe differences between mitosis and meiosis? Select all correct answers.

a. Mitosis produces diploid cells, and meiosis produces haploid cells.

b. Mitosis is involved in asexual reproduction, and meiosis is involved in sexual reproduction.

c. Only body cells result from mitosis, but both body cells and gametes result from meiosis.

d. Mitosis produces genetically unique cells, and meiosis produces genetically identical cells.

e. Two daughter cells are produced by mitosis, and four daughter cells are produced by meiosis.

4. Describe two pieces of evidence to support the claim that sexual reproduction increases genetic variation.

5. Identify the process shown in Figure 18. Then explain how the figure provides evidence to support the claim that meiosis increases genetic variation.

6. Make a table categorizing each of the items in the list as a description of diploid or haploid cells.

- contain single chromosomes, each from one parent
- are described as 2*n*
- make fertilization possible
- result from meiosis
- contain chromosomes in pairs, one from each parent
- are described as *n*
- result from mitosis

7. Why is it important that human gametes have half a set of DNA instead of a full set of DNA? Use scientific reasoning to support your claim.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Inheritable genetic variations result from new genetic combinations made through meiosis and sexual reproduction.

Independent assortment and crossing over are processes that contribute to genetic variation within a species.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how the models and explanations in this lesson can be used to support a claim for how meiosis and sexual reproduction increase genetic variation.

FIGURE 18: This process occurs during meiosis.