SBI3U-C

Meiosis

Introduction

Your life began as a single cell called a zygote, formed from the union of two genetically unique cells: a sperm cell and an egg, also known as sex cells or gametes. Gametes are formed through an important process called meiosis. In this lesson, you will learn about meiosis and meiotic disorders that can change the course of an individual's life.

You will start by learning about the differences between sexual and asexual reproduction. Next, you will review the steps of mitosis, and see how they occur again in the first stage of meiosis. You will also use an online animation to view cells in various stages of meiosis and practise your skills at making biological drawings of what you see. Finally, you will consider the ethical viewpoints surrounding the labelling of some differences in genetics as "disorders."

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Asexual and Sexual Reproduction	¼
Mitosis: A Review	½
Meiosis	1
Activity: Meiosis	½
Mistakes in Meiosis	½
Ethics and Genetic Disorders	½
Key Questions	1

What You Will Learn

After completing this lesson, you will be able to

- use a computer simulation to investigate the process of meiosis and draw biological diagrams to help explain the main phases in the process
- explain the phases in the process of meiosis in terms of cell division, the movement of chromosomes, and crossing over of genetic material
- investigate genetic processes, including those that occur during meiosis, and analyze data to solve basic genetics problems involving monohybrid and dihybrid crosses
- demonstrate an understanding of concepts, processes, and technologies related to the transmission of hereditary characteristics
- describe some genetic disorders caused by chromosomal abnormalities (such as non-disjunction of chromosomes during meiosis) or other genetic mutations in terms of chromosomes affected, physical effects, and treatments

Asexual and Sexual Reproduction

No individual organism can live forever. Chance events, or a gradual breakdown through aging, eventually lead to its death. But species can persist for millions of years because their members reproduce. Without reproduction, life would cease to exist. Also, as you learned in the previous unit, reproduction is essential to the process of evolution. Because of its importance in our lives, and in all of nature, we need to understand how reproduction works, including at the genetic level.

Organisms can reproduce in two ways: asexually or sexually. Asexual reproduction includes any type of reproduction that creates offspring that are identical to the parent. In this unit, we will focus on sexual reproduction, where cells combine to create new, genetically unique organisms.

Sexual Reproduction

Sexual reproduction involves two sexes, producing offspring that are genetically different from both parents and from each other (except in the case of identical twins). This kind of reproduction usually results in greater genetic variation than is possible with asexual reproduction. As a result, sexually-reproducing species can evolve faster than asexually-reproducing ones, and therefore adapt more rapidly to new environmental conditions.

Sexual reproduction requires that each individual produce sex cells called gametes. These are specialized, genetically unique cells used for reproduction. The gametes produced by males are called sperm cells, while female gametes are called egg cells. Gametes are made by reproductive organs called gonads (testes in males, ovaries in females) through the process of meiosis. Fertilization is the process by which gametes from two parents combine to form a new cell called a zygote.

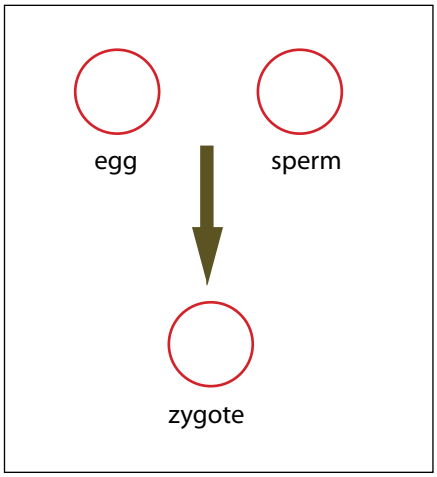


Figure 5.1: Diagram showing a sperm cell and an egg joining together to form a zygote

Chromosomes

Chromosomes are long coiled strands of DNA found in the nucleus of cells. Different species have different numbers of chromosomes. For example, cats have 38, while dogs have 78. The human body has 46 chromosomes, which are arranged into 23 pairs; these are called homologous pairs (Figure 5.2). Each pair is given a number from 1 to 23. When you were born, you received one member of each pair from your mother and one from your father.

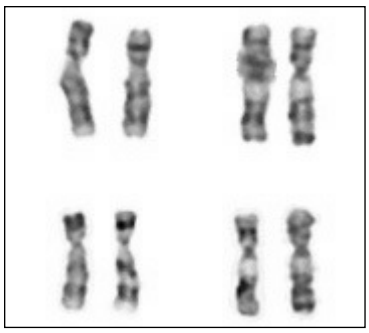


Figure 5.2: Photo showing four pairs of homologous chromosomes that are stained to highlight their features.

Source: Wikimedia Commons

Notice how each member of the homologous pair in Figure 5.2 has a similar shape and shows a similar banding pattern (stripes) when stained. This is how biologists first noticed that chromosomes usually come in pairs.

Each chromosome contains thousands of genes. For example, a gene to determine eye colour may be on chromosome 15. The copy of chromosome 15 that came from your mother may contain the version of the gene (allele) for green eyes, while the copy that came from your father may contain the allele for brown eyes. Your final eye colour is determined by the interaction of the alleles on the two copies of chromosome 15. The two copies of chromosome 15 are called homologous because they are very similar and contain the same kinds of genes. Their similar genetic sequence means they will coil up in similar ways, producing chromosomes that look alike.

Gametes are described as being haploid since they contain only half the number of chromosomes found in the body cells (also called somatic cells). In humans, the gametes contain 23 chromosomes (n = 23) which is half the number found in body cells. Somatic cells are called diploid (2n = 46) since they contain all 46 chromosomes.

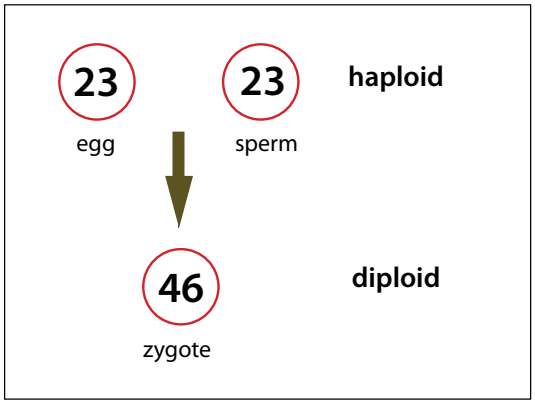


Figure 5.3: Diagram showing two human gametes joining to form a zygote

Mitosis, or cell division, is required for growth, repair and reproduction of cells. Examples include the production of new skin cells as old ones dry out and fall off, and bacteria reproducing to create new bacteria. The new cells created in mitosis are exactly the same as the original cells.

When cells divide by mitosis, they end up with the same number of chromosomes as the parent cell. To create gametes, a process is needed to divide the number of chromosomes in half. This process is called meiosis. Before you study meiosis, you will review mitosis, because there are some similarities.

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

1. What is the main evolutionary benefit of sexual reproduction? Suggested answer
2. What is the difference between sexual reproduction and asexual reproduction? Suggested answer
3. How many chromosomes does a human somatic cell have? How many does a gamete have? Suggested answer

Mitosis: A Review

Mitosis is the division of a cell into two identical daughter cells. Cell division is used to produce new cells for growth and maintenance, to repair damaged cells, and for asexual reproduction.

Before mitosis begins, a cell must first make a copy of its "software," its DNA; this ensures that the daughter cells will both have an exact copy of the original DNA from the mother cell. This copying process, called the synthesis phase, takes time because DNA is a long, complex molecule. (If you could stretch out all the DNA molecules found in a single human cell, the resulting thread would be over one metre long.)

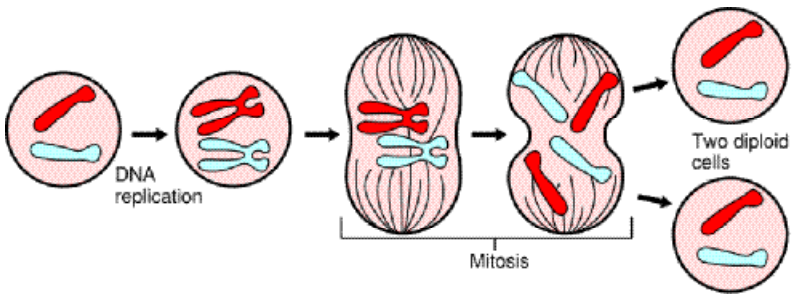


Figure 5.4: Diagram of DNA replication showing how two diploid cells are created

Although mitosis occurs seamlessly and without interruption, scientists divide it into four main sub-phases. These observable sub-phases or stages are illustrated in four diagrams, below, to help you better understand the process. The four stages are prophase, metaphase, anaphase, and telophase.

Prophase

At the start of this stage, the DNA has already been replicated. The two copies stay close together and twist into little X-shaped structures called chromosomes. Like a pair of socks tied together in the middle, a chromosome is made of two identical bundles of DNA called chromatids. The nuclear membrane disappears at the end of prophase, releasing the chromosomes.

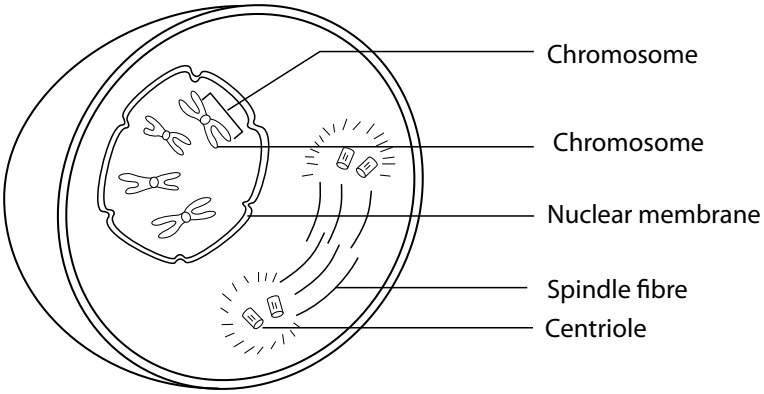


Figure 5.5: Sketch showing the prophase stage of mitosis

In preparation for metaphase, strings of protein called spindle fibres begin to form from centrioles at opposite ends of the cell.

Metaphase

During this stage, the chromosomes line up at the middle of the cell and the spindle fibres attach to the chromosomes.

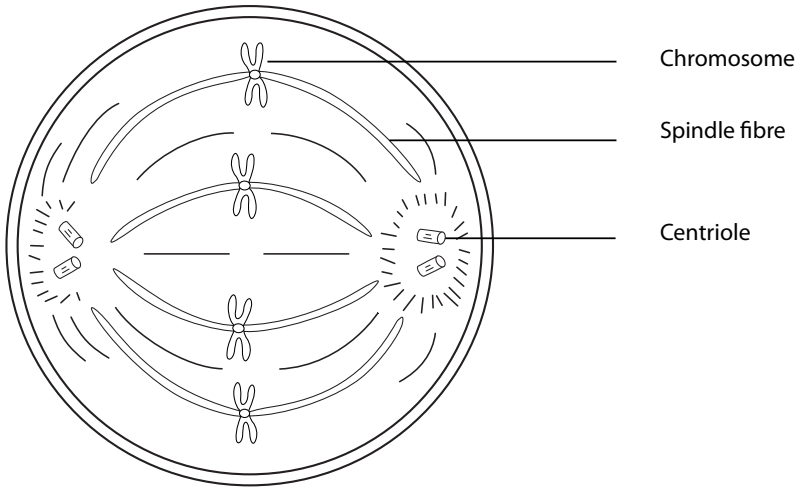


Figure 5.6: Sketch showing the metaphase stage of mitosis

Anaphase

During this stage, the chromosomes are pulled apart into identical halves, called sister chromatids, which are then pulled to opposite ends of the cells by the shrinking spindle fibres.

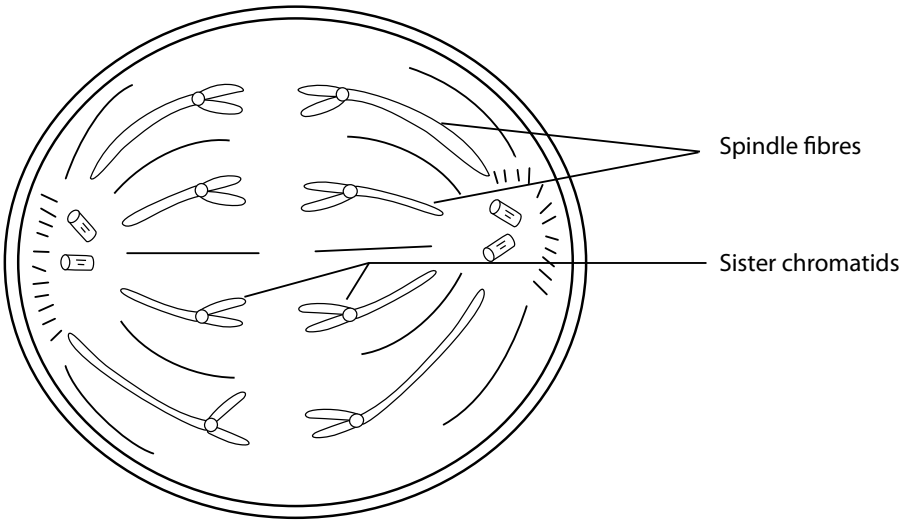


Figure 5.7: Sketch showing the anaphase stage of mitosis

Telophase

During this stage, a nuclear membrane reforms around separated sister chromatids at each end. The two newly-formed nuclei contain matching DNA. Chromosomes uncoil, and the spindle fibres dissolve. The process of cytokinesis (cell division) then begins with the pinching in of the cell membrane at the middle.

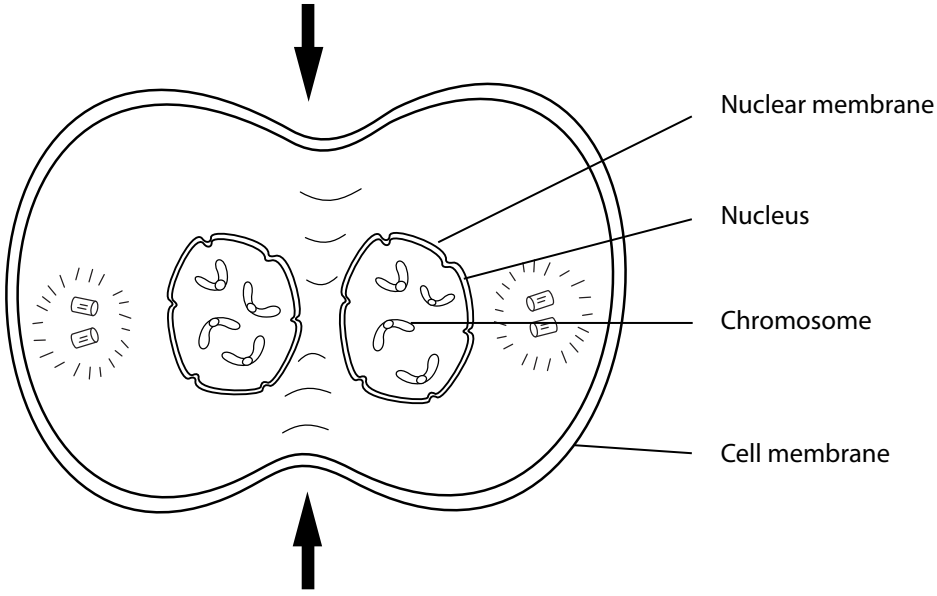


Figure 5.8: Sketch showing the telophase stage of mitosis

Recommended Activity:

Do an Internet search using the terms "mitosis video". Watch a video or two about mitosis to ensure you understand the concept.

Support Questions

4. What is the outcome of mitosis? Suggested answer

Meiosis

Nearly all multicellular organisms, like humans, reproduce sexually by the fusion of an egg and a sperm. In humans, this new cell, called a zygote, contains 46 chromosomes (in 23 pairs). But what about its parent cells, the sperm and egg? If they each had 46 chromosomes, wouldn't their union result in a zygote with 92 chromosomes (46 pairs)—double the usual number? Clearly, this is not what actually happens. Early on, cell biologists realized that in the creation of the sperm and egg cells, there must be a process that cuts the number of chromosomes in half so that this doubling of chromosome number across generations does not occur.

The process, called meiosis, was discovered in 1876. Meiosis is a special kind of cell division that is closely related to mitosis. In preparation for meiosis, the chromosomes are copied once, just like in mitosis; but, instead of one cell division, there are two. The result of meiosis is four daughter cells, each containing 23 individual chromosomes rather than the 46 (in 23 pairs) that were found in the original cell.

Meiosis involves two successive cell divisions (meiosis I and meiosis II), with DNA replication happening only in meiosis I. Both meiosis I and II involve four stages, similar to mitosis. Figure 5.9 provides an overview of the process.

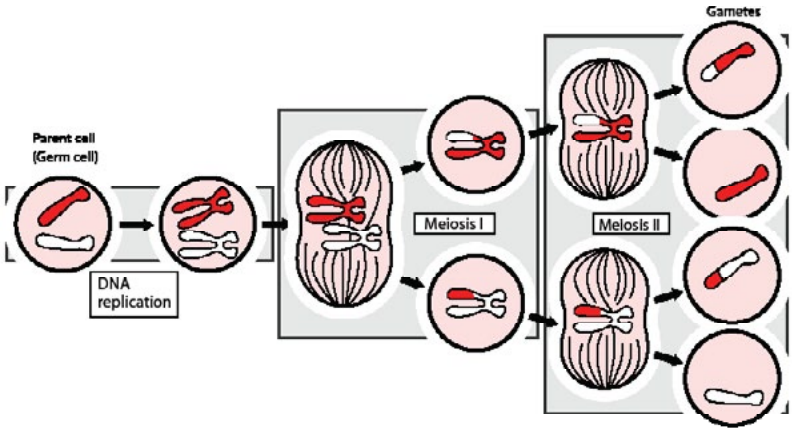


Figure 5.9: Diagram showing an overview of meiosis

Source: Wikimedia Commons

The stages have the same names as in mitosis but there are some differences between them, especially in meiosis I. Also, since there are two cell divisions in meiosis, the name of each stage is followed by I or II, indicating the division to which it belongs.

Meiosis I: First Meiotic Division

This first cell division in meiosis (meiosis I) is similar to mitosis in that it involves DNA duplication and cell division. The difference is that meiosis I results in two daughter cells that have only half the original number of chromosomes of the parent cell, but each chromosome is doubled. An easy way to remember the difference between mitosis and meiosis I is that in mitosis, each chromosome is split apart with one branch going to each daughter cell; whereas, in meiosis I, each chromosome stays intact, but only half the chromosomes move into each daughter cell (Figure 5.10).

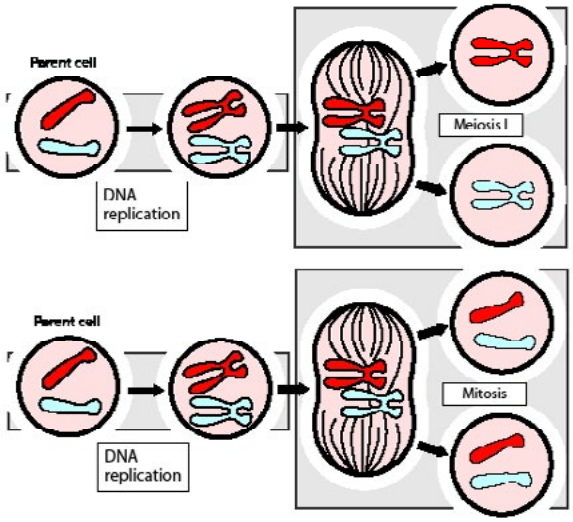


Figure 5.10: Diagram comparing meiosis I with mitosis

Source: ILC, adapted from Wikimedia Commons

Prophase I

At the start of this stage, the chromosomes are already duplicated. These are called sister chromatids. This also happens in mitosis. However, crossing over—the exchange of genetic information between two homologous chromosomes—can also occur during this stage. This is often called recombination, because portions of genetic material switch places between the members of the homologous pair, re-combining the genetic material on each chromosome. This creates genetic variability, as two unique chromosomes are formed. The process of recombination is shown in Figure 5.11, below.

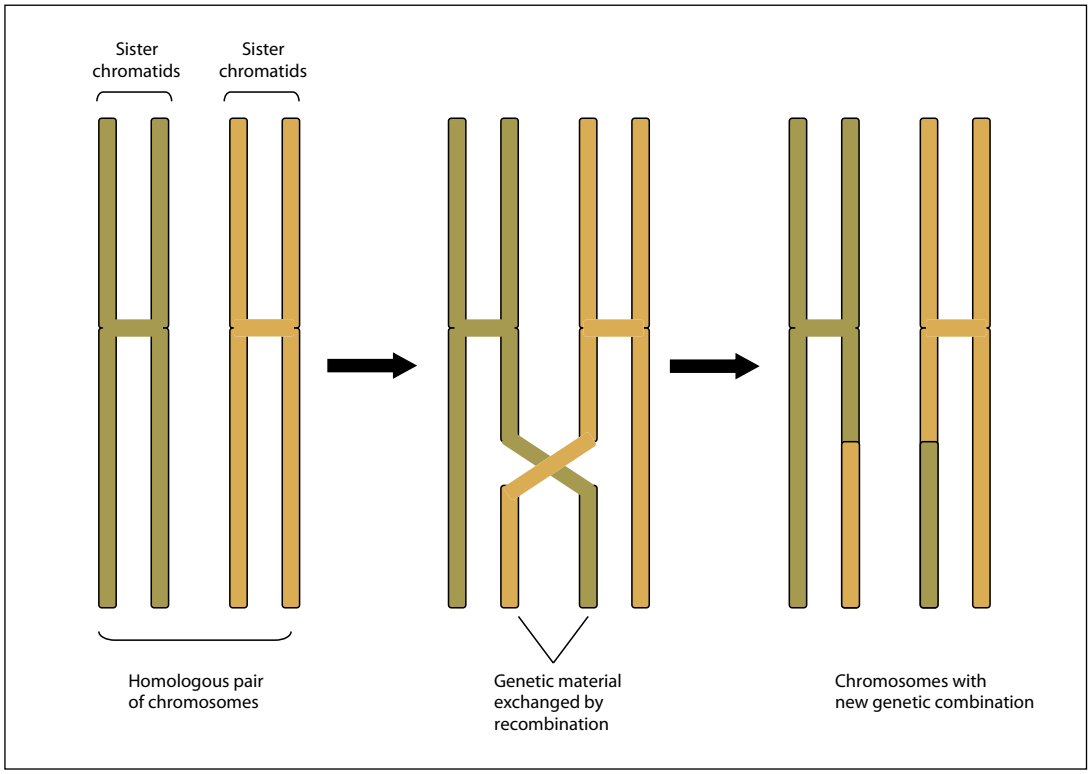


Figure 5.11: Crossing over during prophase I. Maternal genetic material is represented by the solid colour, and paternal material is represented by the checked pattern.

At the end of prophase I, the nuclear membrane disappears and the spindle fibres begin to form from centrioles at opposite ends (poles) of the cell.

Metaphase I

During this stage, homologous chromosomes align at the equator and attach to the spindle fibres.

Anaphase I

During this stage, the homologous pairs of chromosomes are pulled apart by the shrinking spindle fibres, with the sister chromatids remaining bound together. Each chromatid pair moves independently to each pole, so that each daughter cell has an independent assortment of maternal and paternal chromatids.

Telophase I

During this stage, two daughter cells are formed, each containing only one chromosome of the homologous pair. The number of chromosomes is thus divided in half (from diploid to haploid).

Meiosis II: Second Meiotic Division

In the second cell division, meiosis II, the gametes are formed, each with only half the number of chromosomes as the parent (Figure 5.9). Meiosis II is also made up of four stages: prophase II, metaphase II, anaphase II, and telophase II. These stages are very similar to those of meiosis I.

Prophase II

During this stage, the nuclear membrane disappears and the chromatids shorten and thicken, but there is no duplication of DNA. The spindle fibres begin to form from centrioles at opposite poles of the cell.

Metaphase II

During this stage, chromosomes align at the equator and attach to the spindle fibres.

Anaphase II

During this stage, the chromosomes are pulled apart by the spindle fibres and the sister chromatids migrate separately to each pole.

Telophase II

At this stage, cell division is complete and four haploid daughter cells are produced. The daughter cells (gametes) have half the number of chromosomes found in the original parent cell and, if they experienced crossing over, they can be genetically different from the parent cell.

The primary difference between meiosis and mitosis is that in meiosis there are two cell divisions, resulting in gamete cells with a haploid number of chromosomes.

Sexual Reproduction Creates Variation in Three Ways

1. Crossover during prophase I of meiosis ensures a mixing of the maternal and paternal genes on chromosomes.
2. Independent assortment of maternal and paternal chromosomes at metaphase I/anaphase I of meiosis ensures a mixing of the maternal and paternal chromosomes in the gametes.
3. The fusion of egg and sperm chromosomes from two different individuals into a single cell (zygote) creates a new genetic combination.

Support Questions

5. Describe the main results of meiosis. Suggested answer

6. Complete the table below summarizing the principle differences between mitosis and meiosis. Suggested answer

	Mitosis	Meiosis
Purpose		
Number of daughter cells		
Chromosome number		
Number of cell divisions		
Genetic content		

7. Complete the table below using the information provided. The information for humans has been included as a guide. Suggested answer

	Human	Cat	Shrimp	Bean
Before meiosis				
Chromosome number	46			
Number of pairs of homologous chromosomes	23		127	
After meiosis I				
Chromosome number	23	19		
After meiosis II				
Chromosome number	23			11
Number of pairs of homologous chromosomes	0			

8. How does crossing over create greater genetic diversity for natural selection to act upon? Suggested answer

Activity: Meiosis

Now perform the following activity on Meiosis, then answer the following Support Questions.

Support Questions

9. **a)** Make a drawing of the cells at all four stages of the second meiotic division: prophase II, metaphase II, anaphase II, and telophase II. Label the chromosomes to indicate the maternal and paternal chromosomes as they move through the process.

b) Describe the main events occurring at each stage. Suggested answer

In case you need one, here is a refresher on how to make a biological drawing.

Mistakes in Meiosis

During meiosis, mistakes sometimes occur when chromosomes separate improperly during division. Errors that result in a heritable change in the molecular structure of DNA are called mutations. Many mutations change the appearance of the organism.

Nondisjunction

Mistakes in meiosis can result in an abnormal number of chromosomes in an egg or sperm cell. If this gamete is involved in fertilization, the child produced from this zygote will have cells with too few or too many chromosomes, a condition known as aneuploidy. Aneuploidy is caused by a mistake in the meiotic process known as nondisjunction—the failure of the homologous chromosomes to move apart properly during meiosis. If the gamete is missing a chromosome, the resulting child will have only one copy of a particular chromosome, a condition known as monosomy. Conversely, if the gamete has an extra chromosome, the resulting child will have three copies of a particular chromosome, a condition known as trisomy. Nondisjunction can occur during meiosis I or II (Figure 5.12). In either monosomy or trisomy, if the child survives, he or she will show effects associated with the genetic information that is carried on the chromosome involved.

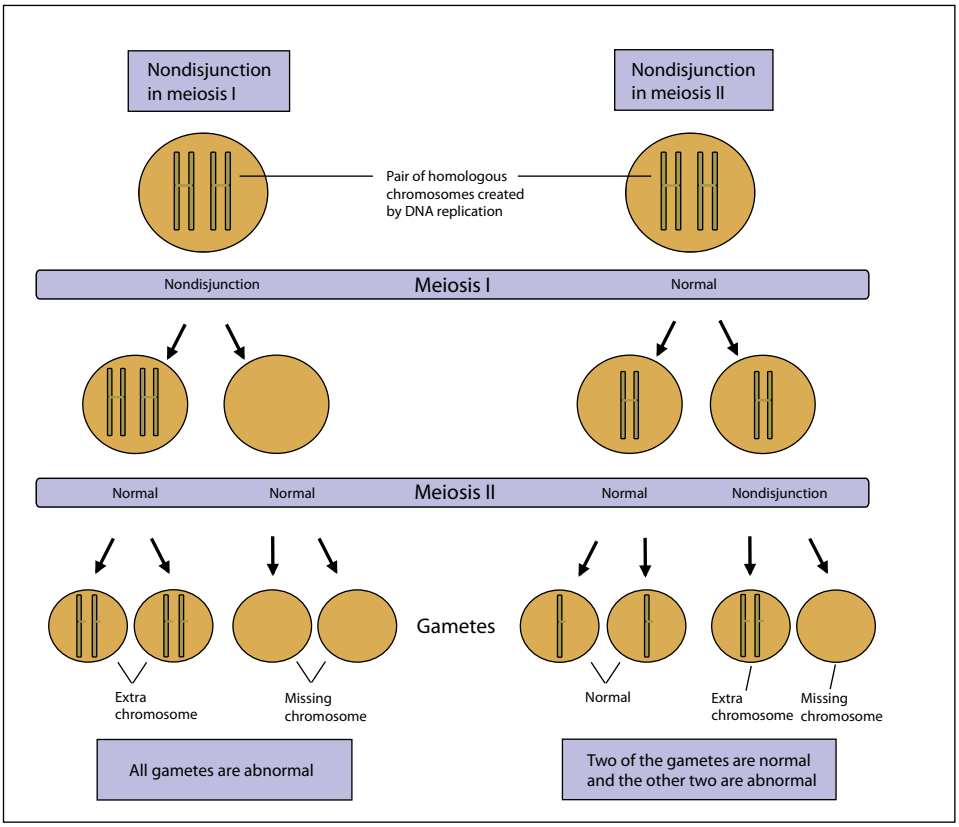


Figure 5.12: Diagram showing nondisjunction in meiosis I and II

Nondisjunction can happen to any of our 23 pairs of chromosomes. The first 22 are simply numbered 1 through 22. The last pair are called the sex chromosomes, or X and Y chromosomes (because they look like the letters X and Y). Females have two X chromosomes in this pair; males have one X and one Y chromosome (Figure 5.13).

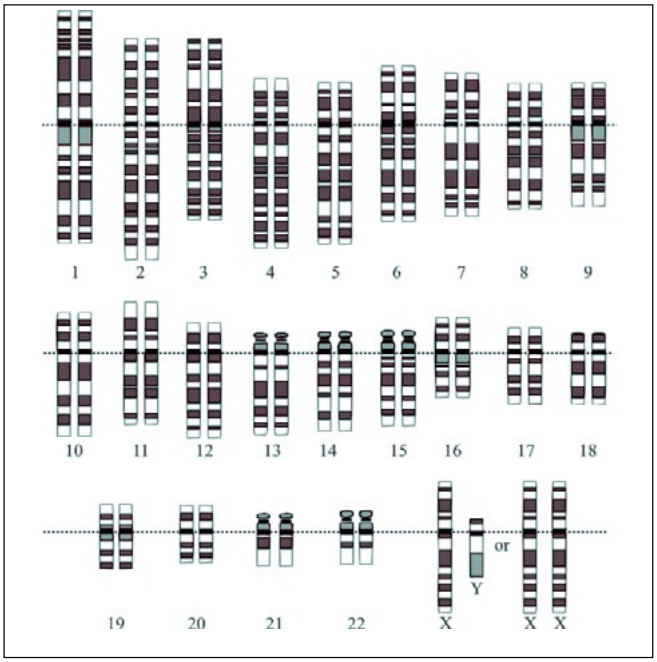


Figure 5.13: Diagram showing an entire set of human chromosomes

It is just a matter of chance whether nondisjunction happens with the maternal copy or the paternal copy of the chromosome in meiosis II. It doesn't matter, because the results are the same, with some gametes missing a copy of the chromosome and some having two copies (Figure 5.14).

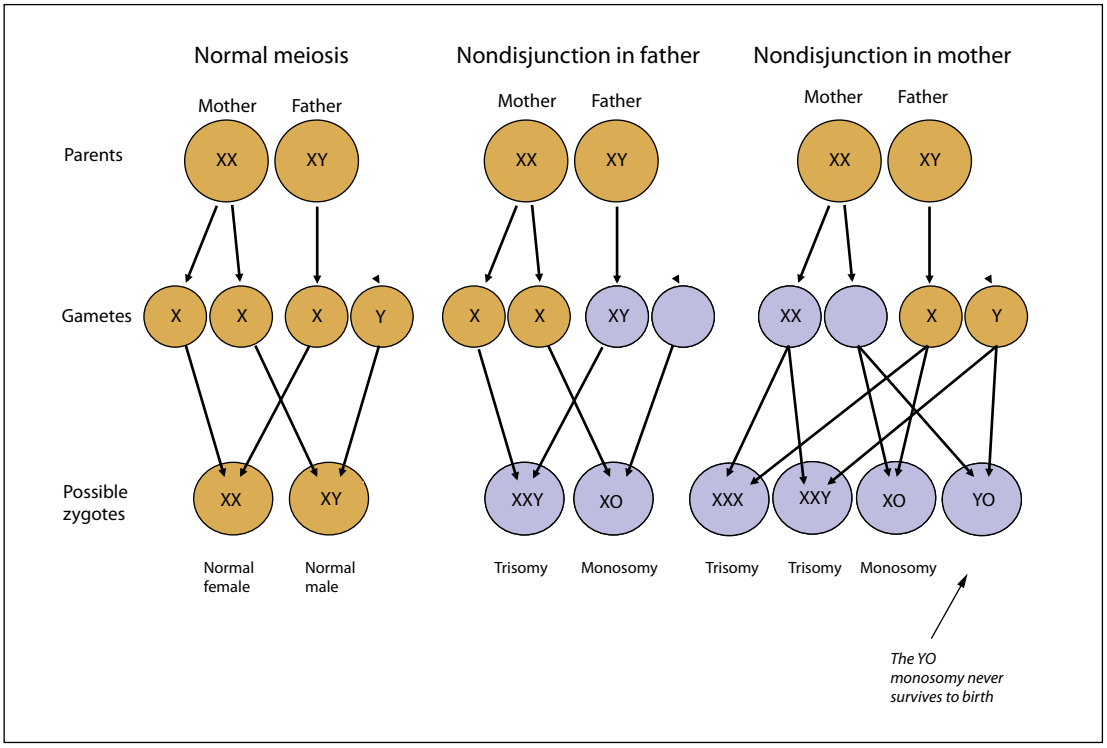


Figure 5.14: Diagram showing nondisjunction in meiosis I and II

Recommended Activity:

To see and hear this diagram explained, watch this pencast video. (Make sure you have the latest version of Adobe Reader.)

If nondisjunction occurs with the sex chromosomes, this has the potential to produce disorders related to sexual development, including infertility, as you will see below.

Disorders Caused by Nondisjunction

Down Syndrome

Down syndrome is a disorder that results from a trisomy in which the zygote receives three chromosomes for chromosome pair number 21. Characteristics of this disorder include cognitive disability, short limbs, an unusually round face, abnormally shaped eyelids, and a shorter expected lifespan. Cognitive disability may be mild or profound. Approximately 1 in 800 babies are born with Down syndrome.

Turner Syndrome

Turner syndrome occurs when sex chromosomes undergo nondisjunction resulting in a monosomy for the X chromosome. This produces a female with only one X chromosome (XO) instead of the normal two (XX). Women with Turner syndrome do not usually develop sexually (they are sterile), and tend to be short and have thick, wide necks with additional skin folds. Approximately 1 in 2000 to 1 in 2500 female babies are born with Turner syndrome.

Klinefelter Syndrome

Klinefelter syndrome occurs when sex chromosomes undergo nondisjunction resulting in a trisomy which produces a male with two X chromosomes and a single Y chromosome (XXY) instead of the normal two (XY). Men with Klinefelter syndrome produce less testosterone and have reduced fertility compared to XY males, and may also have other symptoms such as enlarged breasts and learning difficulties, although the condition varies widely from person to person. Approximately 1 in 500 to 1 in 1000 male babies are born with Klinefelter syndrome.

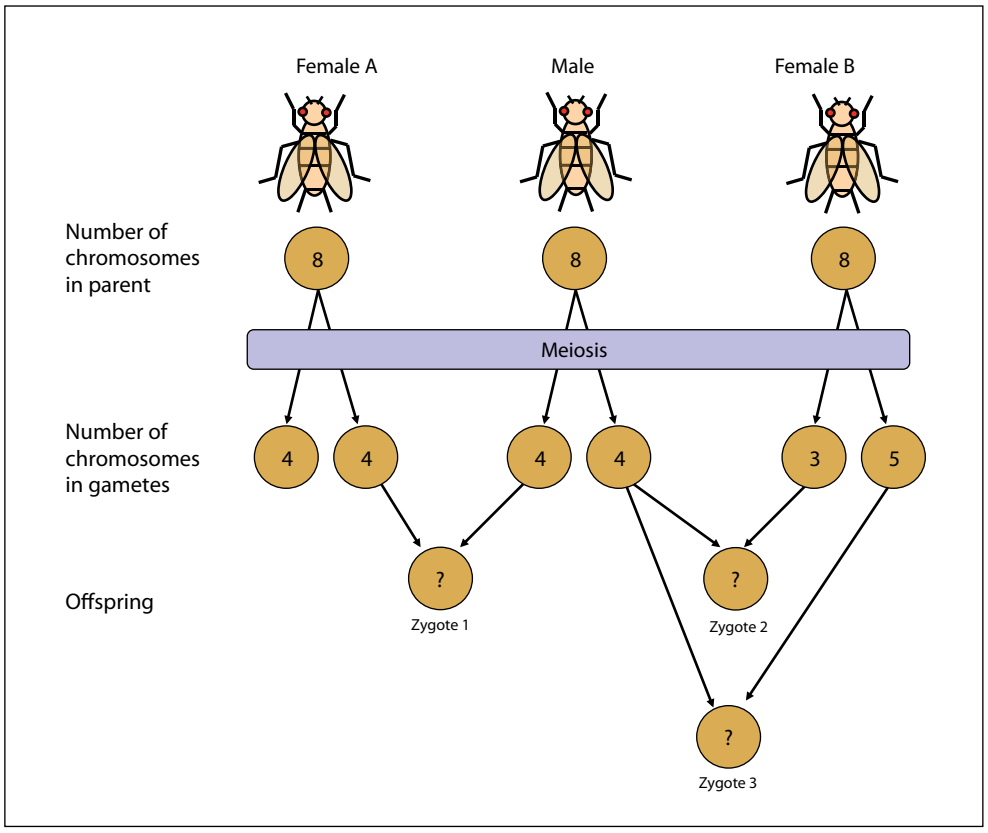
Support Questions

10. **a)** Explain how the process of nondisjunction can result in an individual with Turner syndrome. Create a diagram showing the nondisjunction occurring in the father to help explain your answer.

b) Why is an individual with Turner syndrome sterile?

Suggested answer

11. Fruit flies normally have eight chromosomes. The diagram below shows the result of meiosis in three fruit flies to produce gametes with the number of chromosomes indicated. The male then mates with both female A and female B to produce three zygotes (1, 2, and 3).



a) In which parent did nondisjunction take place?

b) How many chromosomes would be in zygotes 1, 2, and 3 respectively?

c) Which zygote would be most likely to be healthy? Explain.

Suggested answer

d) Name the conditions the other two zygotes have.

Ethics and Genetic Disorders

As you have learned, Down syndrome is a genetic disorder that occurs when there is an error in an important cellular process called meiosis. Individuals affected by Down syndrome have a wide range of abilities, but are generally identified by common traits including lower cognitive abilities.

Recent advances in medicine have researchers confident that they could minimize if not cure the symptoms of Down syndrome, which seems like good news—however, there is a growing group of people that feel there is nothing to cure. They argue that genetic disorders are not "diseases" at all, just different expressions of the human genetic makeup.

Jenn Power, a Canadian mother of twin boys with Down syndrome, responded to the news of a cure with this statement (follow the link to read it and hear a recording of it).

Although most doctors understand Ms Power's position, they argue their goal is not to change personalities, but to help these individuals lead more independent lives.

Support Questions

12. There are a growing number of individuals who feel that doctors should no longer try to cure Down syndrome, stating they feel that it is not really a disorder. State two possible reasons people may feel this way, and two possible reasons some may want to seek a cure.

Suggested answer

13. Explain how the process of nondisjunction can result in an individual with Down syndrome. Use a diagram to explain your answer.

Suggested answer

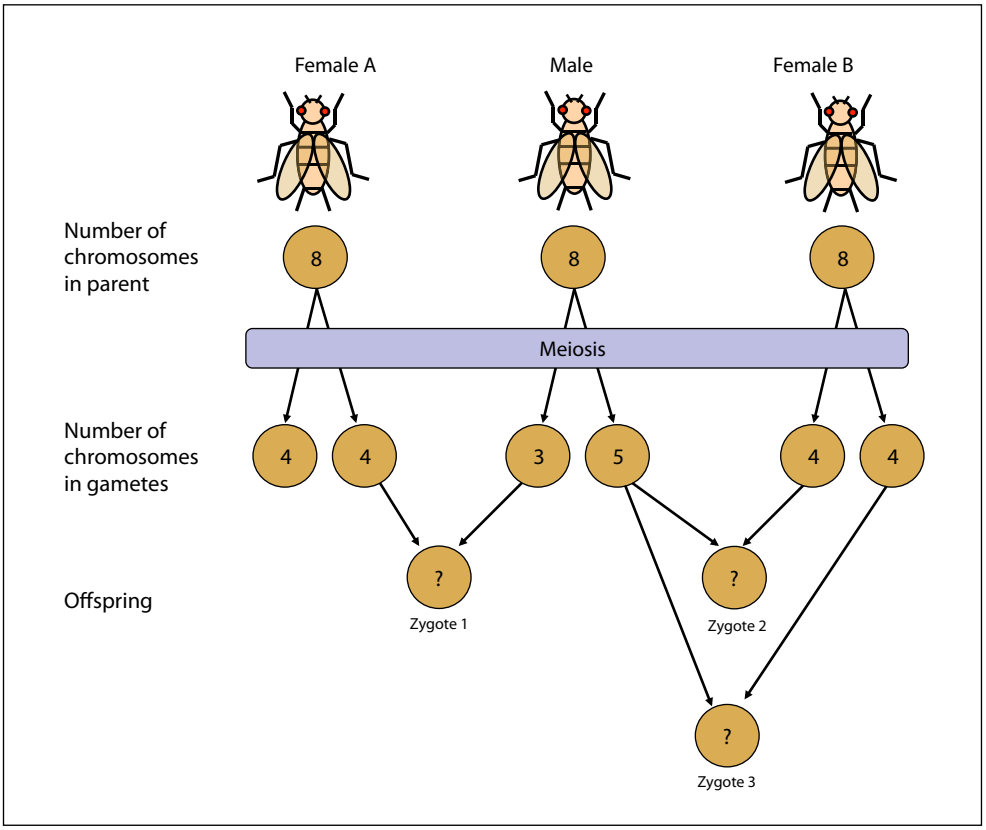
Key Questions

Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

(15 marks)

16. Describe two evolutionary consequences if the process of crossing over in meiosis ceased to occur. **(2 marks)**

17. Fruit flies normally have eight chromosomes. The diagram below shows the result of meiosis in three fruit flies to produce gametes with the number of chromosomes indicated. The male then mates with both female A and female B to produce three zygotes (1, 2, and 3).



a) In which parent did nondisjunction take place? **(2 marks)**

b) How many chromosomes would be in zygote 1, 2, and 3? **(3 marks)**

c) Which zygote, if any, would be most likely to be healthy? Explain. **(2 marks)**

d) Name the conditions the non-healthy zygotes have. **(2 marks)**

18. **a)** Explain how the process of nondisjunction can result in an individual with Klinefelter syndrome. Create a diagram showing the disjunction occurring in the mother to help explain your answer. **(3 marks)**

b) Why is an individual with Klinefelter syndrome sterile? **(1 mark)**

Now go on to Lesson 6. Send your answers to the Key Questions to the ILC when you have completed Unit 2 (Lessons 5 to 8).