6.1 Meiosis

The process of meiosis results in the production of special cells called gametes. Gametes have half the number of chromosomes as body cells. Cell division occurs twice in meiosis: once at the end of meiosis I and again at the end of meiosis II. In meiosis I, matching pairs of chromosomes called homologous chromosomes separate. In meiosis II, sister chromatids separate. The process of meiosis shuffles genetic information and results in variation in the gametes.

Words to Know

diploid number
embryo
fertilization
gametes
genetic diversity
haploid number
homologous chromosomes
sexual reproduction
zygote

When you look around your classroom, you will see students of differing heights, facial features, and hair colour. When you look at the photographs in Figure 6.1, you will see some organisms from the same species that look quite different from one another and some that look the same. What do all of these organisms have in common? They have all been produced by a process called **sexual reproduction**. Unlike asexual reproduction, which requires only one parent and produces identical offspring, sexual reproduction requires two parents. Sexual reproduction produces offspring that are genetically different from each other, from either parent, and from any other member of their species. Sometimes these genetic differences are visible, such as the coat colour of the llamas in Figure 6.1A. Sometimes, genetic differences are not visible, such as in the owls in Figure 6.1B.

Figure 6.1A Offspring that result from sexual reproduction are genetically different.

Figure 6.1B Genetic differences may or may not be visible.

Variation, or inherited genetic differences in a species, is called **genetic diversity**. Genetic diversity is the result of sexual reproduction, which randomly sorts, or shuffles, DNA. Because of the combination of genes received from its parents, an organism may be better equipped to cope with changes in its environment. Therefore, one organism of a species may gain an advantage over another organism of the same species.

6-1A Eating Like a Bird

Find Out ACTIVITY

The genetic variation that results from sexual reproduction can give an organism a survival advantage. An organism may be stronger, better at escaping predators, or more skilled at obtaining food. In certain species of birds, for example, variation in beak size and shape can help a species survive in an environment with a specific food source. In this activity, you will determine which type of beak provides a survival advantage for a bird given a particular food source.

Safety

- Never eat anything in the science room.

Materials

- spoon
- chopsticks (one set)
- forceps or tweezers (one pair)
- marbles
- toothpicks
- cereal
- pennies
- timer

What to Do

1. Work in a group of four. Predict which "beak" (spoon, chopsticks, or forceps) will pick up each of the "foods" (marbles, toothpicks, cereal, pennies) the best. Record your predictions.
2. Design a chart to record data on how much food is collected with each type of beak.
3. Put the food in a pile in the middle of a table top. Three members of your group will each use one of the beaks to pick up food from the pile. The fourth person will time the group members for 1 min as they race to pick up as much food as possible. The fourth person will then record the data.
4. Decide on the best type of graph to illustrate your group's data. Construct a graph to display the data.
5. Clean up and put away the equipment you have used.

Science Skills

Go to Science Skill 5 for information about how to organize your data into a graph.

What Did You Find Out?

1. Did your group's predictions match your results? Explain.
2. Compare your group's results with those of two other groups.
   (a) How are the results the same?
   (b) How are the results different?
3. Which beak would provide a survival advantage in an environment where marbles are the only food source? Explain.
4. Which beak would provide a survival advantage in an environment where toothpicks are the only food source? Explain.

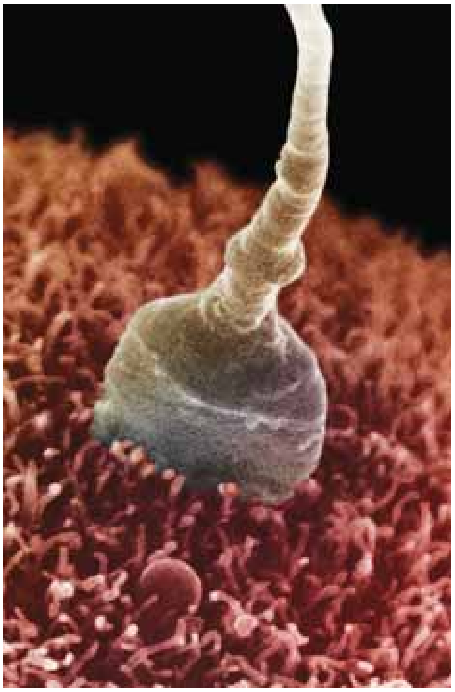


Figure 6.2 A human sperm enters a human egg cell, resulting in fertilization.

The Role of Gametes

Genetic information is passed along in the chromosomes an offspring inherits from its parents. In section 4.1, you learned that all organisms have a specific number of chromosomes in their body cells. In eukaryotic organisms, this chromosome number is referred to as the **diploid number** ($2n$). Diploid means that a body cell has two sets of chromosomes. The diploid number for humans is 46, or 2×23 chromosomes. Mitosis ensures that the diploid number always stays the same and that the genetic information contained within your body cells also remains the same, unless a mutation occurs.

So what makes humans genetically different from each other? Humans inherit one set of 23 chromosomes from their female parent and one set of 23 chromosomes from their male parent. Each set of these inherited chromosomes is referred to as the **haploid number** (n). Haploid chromosomes are carried in **gametes**, which are specialized cells necessary for reproduction. In animals, male gametes are called sperm cells and female gametes are called egg cells.

During a process called **fertilization**, an egg cell is penetrated by a sperm cell (Figure 6.2), and the haploid genetic information of both male and female gametes combines. The result of this process is a diploid cell called a **zygote**. A zygote receives half its chromosomes from its female parent and half from its male parent. The zygote then undergoes mitosis and cell division and develops into an **embryo**.

Figure 6.3 shows how a zygote inherits its diploid number and develops into an organism.

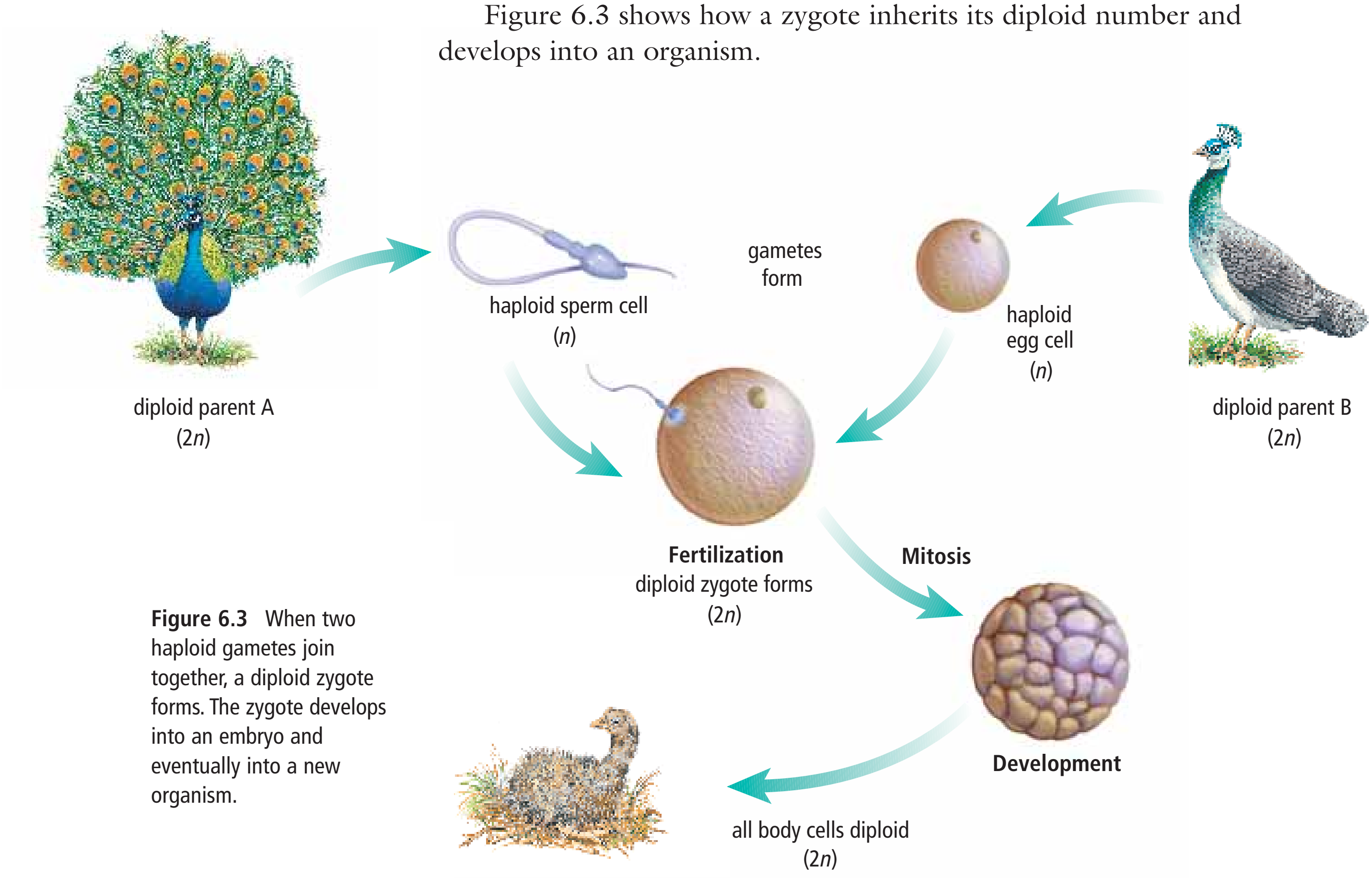


Figure 6.3 When two haploid gametes join together, a diploid zygote forms. The zygote develops into an embryo and eventually into a new organism.

Meiosis: Reducing Chromosome Number

The process that produces gametes with half the number of chromosomes as body cells is called **meiosis**. Without meiosis, the joining of a sperm cell and an egg cell during fertilization would produce an offspring with two times the original number of chromosomes as its parents. Figure 6.4 shows how meiosis produces gametes with half the number of chromosomes of the parent cells. As you look at the figure, notice that DNA replicates only once in the process, even though two cell divisions occur.

Word Connect

"Meiosis" is derived from the Greek word *meion*, which means to reduce.

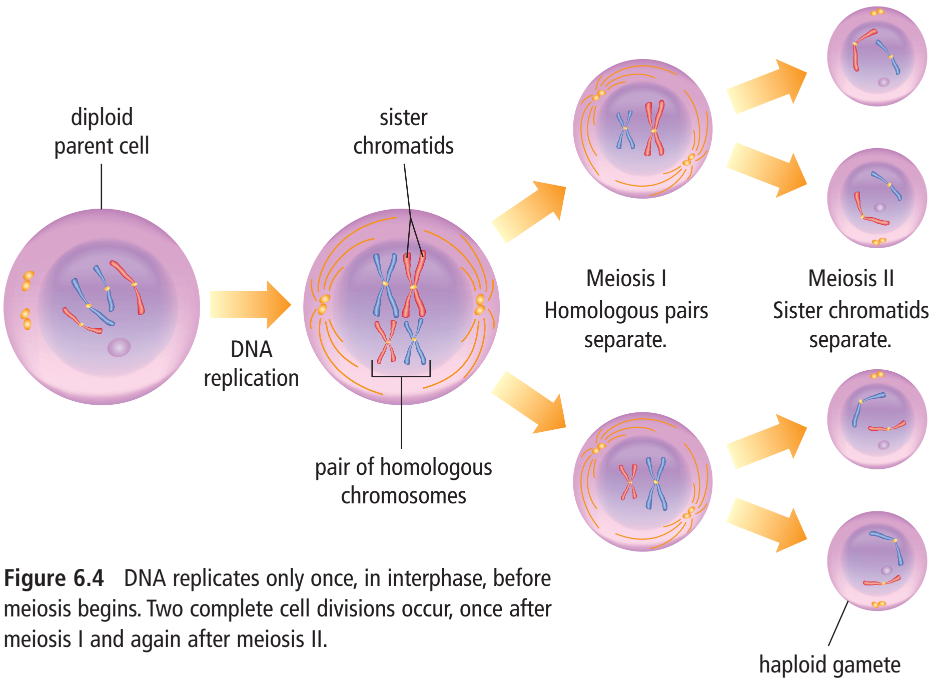


Figure 6.4 DNA replicates only once, in interphase, before meiosis begins. Two complete cell divisions occur, once after meiosis I and again after meiosis II.

Meiosis I

In Chapter 5, you saw that in mitosis each of the 46 chromosomes lines up along the equator of the cell during metaphase. The sister chromatids then move to opposite poles of the cell. Meiosis I differs from mitosis because in meiosis I a pair of matching chromosomes, one chromosome from each parent, lines up at the equator. Scientists refer to this pair of matching chromosomes as a pair of **homologous chromosomes** (Figure 6.5). In meiosis I, the homologous chromosome pair separates and moves to opposite poles of the cell. Two daughter cells result from meiosis I.

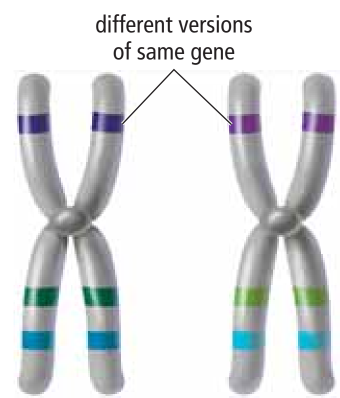


Figure 6.5 Homologous pairs are the same size and shape and have genes in the same location, as shown by the coloured bands in this illustration. Each chromosome may have different versions of those genes, as shown by the different shades of each colour.

Meiosis II

DNA is not replicated again before meiosis II begins. Chemical messages trigger the cells to begin the cell division process. Meiosis II is like mitosis because in both processes the chromatids of each chromosome are pulled to opposite poles. Each daughter cell inherits one chromatid from each chromosome. The result is four haploid cells, each with half the number of chromosomes.

Events in Meiosis that Produce Variation

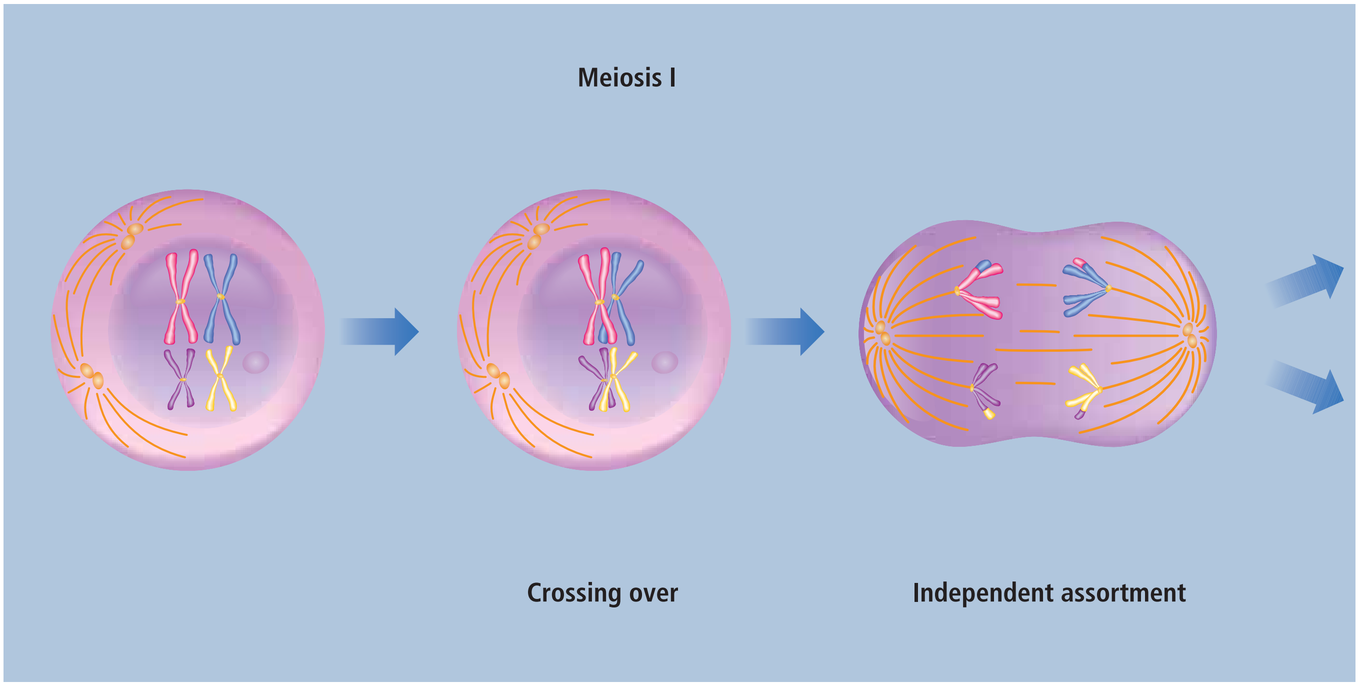


Figure 6.6A In crossing over, non-sister chromatids exchange DNA. In independent assortment, homologous chromosomes separate. Both events result in variation in gametes.

Crossing over

Crossing over is an important event that occurs between each chromosome pair in meiosis I. In crossing over, parts of non-sister chromatids "cross over" each other and exchange segments of DNA (Figure 6.6A). As a result of this exchange, each chromosome picks up new genetic information from the other. Multiple crossovers can occur between two chromosomes. Therefore, crossing over creates an infinite number of genetic possibilities for just one gamete and results in variation.

Independent assortment

Another important event occurs in meiosis I and produces variation. It is called **independent assortment**. During this event, homologous pairs of chromosomes separate at the equator and move toward opposite poles of the cell (Figure 6.6A). For each of the 23 pairs of human chromosomes, there are two possibilities for how a chromosome will eventually sort itself into the daughter cells (Figure 6.6B on the next page). There are more than 8 million combinations possible for these 23 pairs in any egg or sperm cell. When fertilization occurs, 70 trillion different zygotes are possible from the combination of one sperm cell and one egg cell! This explains why people look different from each other and why even brothers and sisters do not look the same.

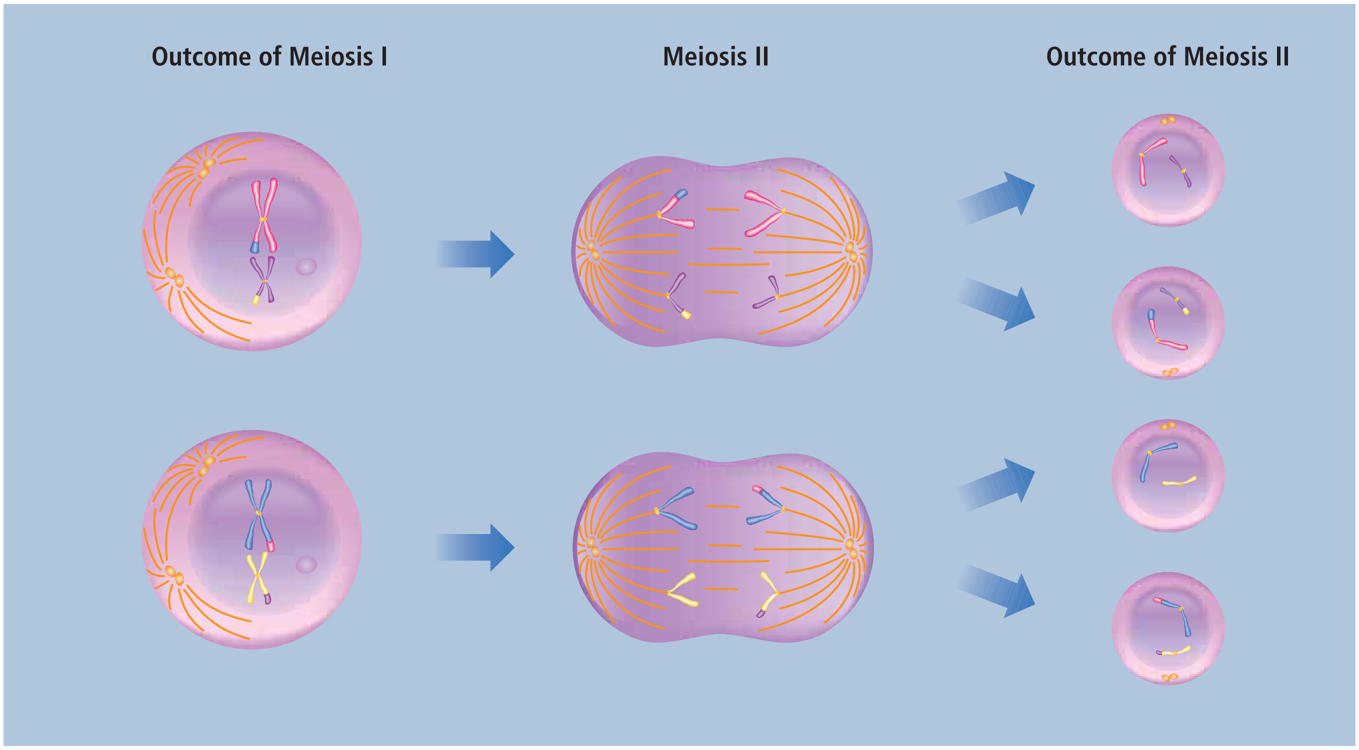


Figure 6.6B After meiosis, chromosomes separate and sort themselves into daughter cells.

Gamete formation

Although the process of meiosis is the same for males and females, gamete formation is different (Figure 6.7). In males, meiosis I occurs and produces two cells. It is immediately followed by meiosis II if there are enough nutrients for cell division. The result is four cells with the cytoplasm and organelles equally divided among them. All four cells may develop into mature sperm.

In females, meiosis I occurs and produces two egg cells, but there is an unequal division of the cytoplasm and organelles. Following meiosis II, three of the cells will disintegrate. The remaining one large egg cell retains most of the cytoplasm and is available for fertilization.

Suggested Activities

Conduct an Investigation 6-1C on page 198
Conduct an Investigation 6-1D on page 200

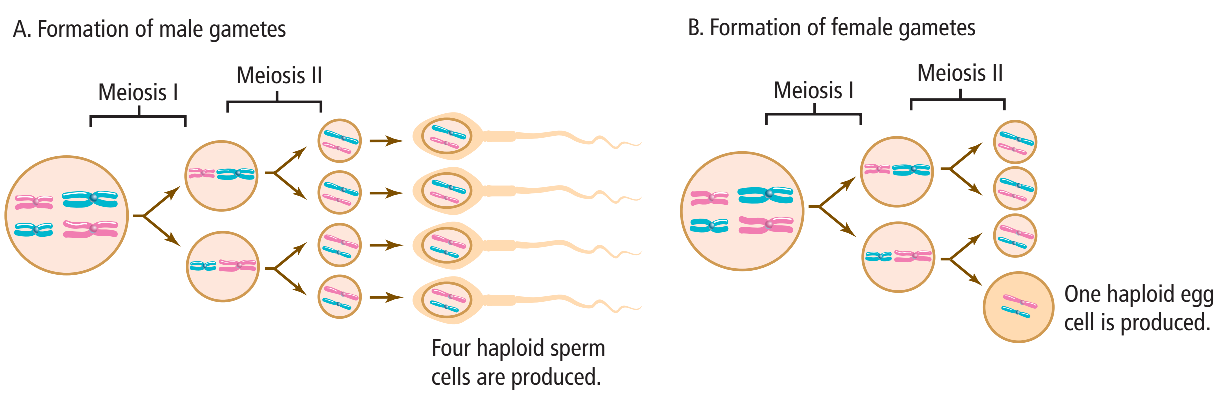


Figure 6.7 Meiosis occurs continuously in the testes of human males from puberty. In females, meiosis begins in the ovaries before birth, then stops until puberty and the onset of the menstrual cycle.

Reading Check

1. What does the term genetic diversity mean?
2. What is the function of meiosis?
3. (a) What is the haploid number of chromosomes in humans?
   (b) What is the diploid number of chromosomes in humans?
4. What is another name for a fertilized egg?
5. What are homologous chromosomes?

Chromosome Mutations in Meiosis

In Chapter 4, you learned that small mutations in genes may have no effect on an organism or may cause disease. Big changes in the organization of DNA and genes happen when pieces of chromosomes are lost, duplicated, or moved within a chromosome or moved to another chromosome. These changes often occur during meiosis. They affect many genes in the chromosome and change the proteins made by those genes (Figure 6.8).

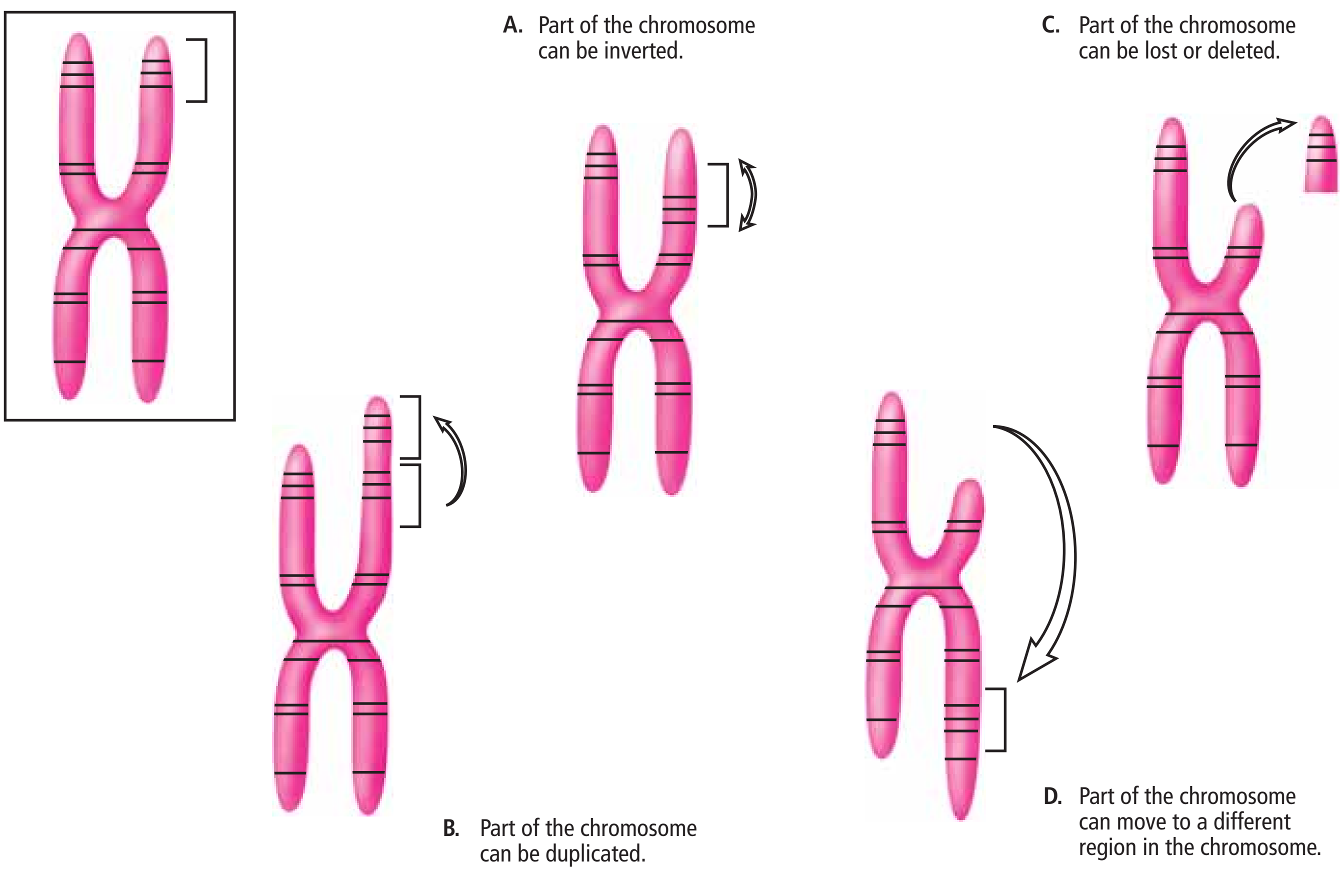


Figure 6.8 Several types of chromosome mutations

Chromosome mutations also occur when cells are exposed to mutagens such as radiation or chemicals. The effect of chromosome mutation can be seen in fruit flies exposed to mutagens. Some mutant fruit flies have legs growing where antennae should be (Figure 6.9). Others, called shar-pei mutants, have wrinkled heads that look like the wrinkled heads of a type of dog known as a shar-pei. Chromosome mutations are frequently seen in the eye colour of fruit flies. Normal fruit flies have brick red eyes. Mutant fruit flies have pink, purple, maroon, or green eyes. Some mutant fruit flies have perfectly functional eyes growing out of their wings.

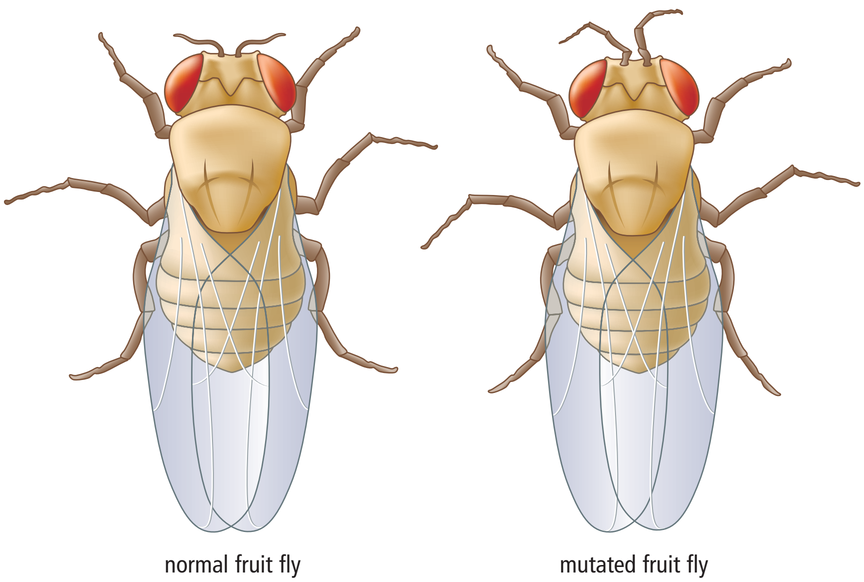


Figure 6.9 An example of chromosome mutation in fruit flies. The fruit fly on the right has legs growing where antennae should be.

Whole chromosome mutations can occur in meiosis I (when homologous chromosomes fail to separate) or in meiosis II (when sister chromatids fail to separate). The result is that one gamete will have two copies of one chromosome and the other will have no copy of that chromosome. Many chromosome mutations are not passed from one generation to the next. For example, large chromosome errors are prevented from being passed along because the offspring either fails to develop or does not live to reach reproductive age and adulthood.

internet connect

Drosophilists are scientists who study fruit flies to understand how mutation occurs. Scientists can produce mutations in fruit flies to learn what happens when a gene stops functioning and no longer produces a specific protein. To learn more about fruit fly genetics, go to **www.bcscience9.ca.**

Figure 6.10 Males and females have specific karyotypes.

Diagnosing Genetic Disorders

Figure 6.10 shows a picture of two teenagers. A geneticist can prepare a different type of picture of these individuals, one that shows all of their chromosomes arranged in a particular order. This picture is called a **karyotype** and is shown in Figure 6.11. Karyotypes are prepared by cutting and pasting chromosomes taken from body cells during mitosis. The homologous chromosomes are identified and paired by size, centromere location, and banding patterns.

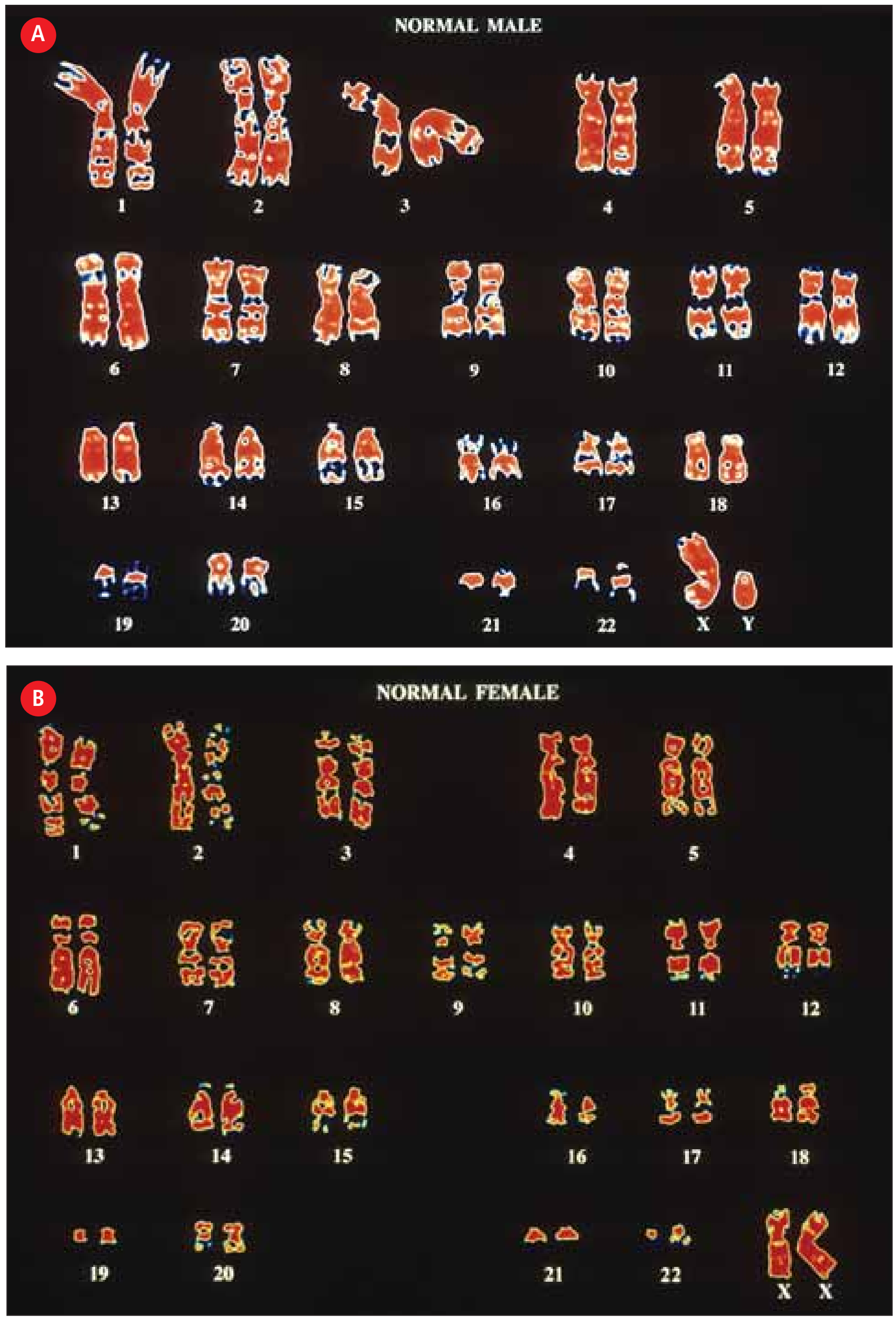


Figure 6.11 Karyotype of a normal male (A) and a normal female (B)

By analyzing karyotypes, geneticists can determine when a whole chromosome mutation has occurred. Understanding which chromosomes have been affected helps physicians diagnose and treat patients with genetic disorders or **syndromes**. A syndrome is a particular disease or disorder with a specific group of symptoms that occur together. One example is Down syndrome, which is one of the most frequently occurring types of chromosome mutations. Individuals with Down syndrome (Figure 6.12) have characteristic facial features and shorter stature and may be prone to developing heart defects and diseases such as Alzheimer's and leukemia. Ninety-five percent of the cases of Down syndrome are caused by an extra 21st chromosome (Figure 6.13).

Figure 6.12 People with Down syndrome are active participants in their communities.

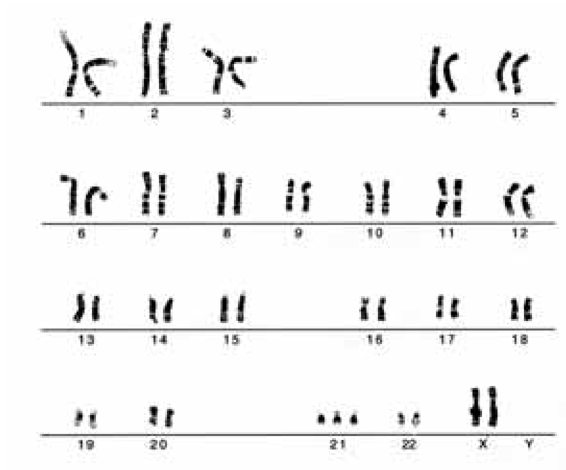
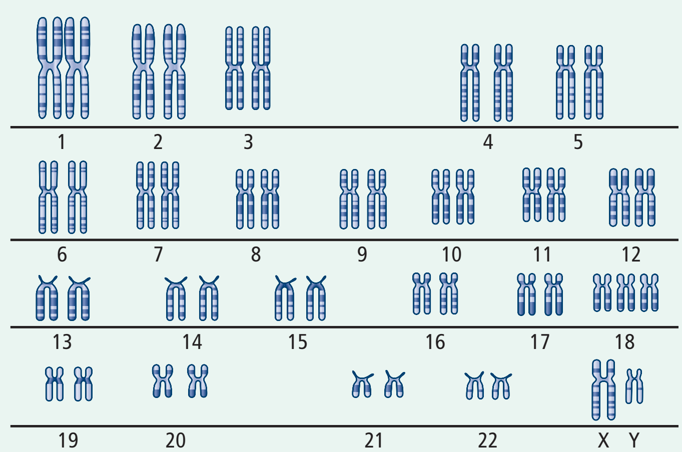


Figure 6.13 The karyotype of a person with Down syndrome

6-1B Analyzing a Karyotype

Find Out ACTIVITY

Geneticists study karyotypes to determine if any chromosome mutations have occurred. In this activity, you will analyze a karyotype of Edwards syndrome.



What to Do

1. Examine the karyotype of Edwards syndrome (right).
2. Count and record the total number of chromosomes and chromosome pairs.
3. Determine whether the individual is male or female.

What Did You Find Out?

1. What chromosome error did you identify?
2. (a) Would karyotyping identify a gene mutation?
   (b) Why or why not?

6-1C Comparing Mitosis and Meiosis

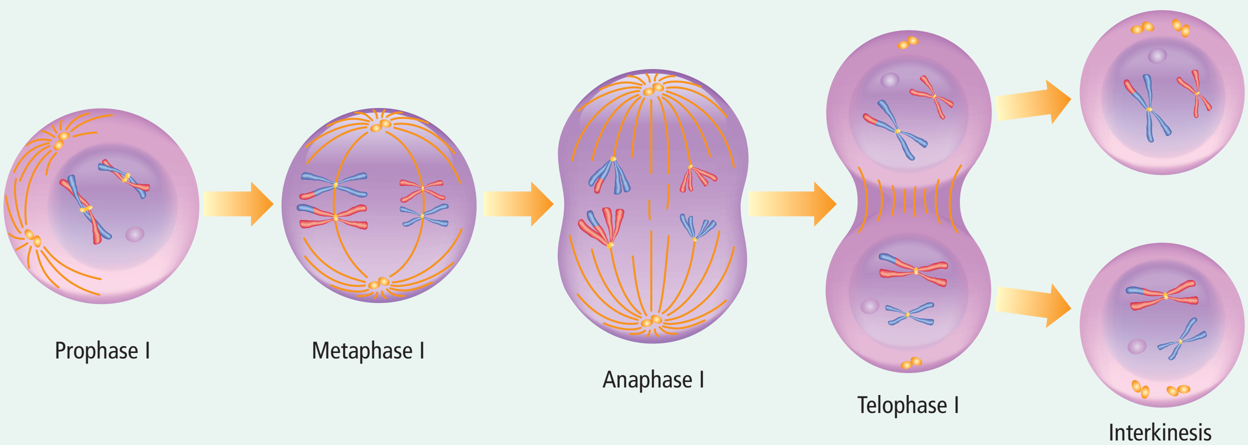
SkillCheck
- Classifying
- Communicating
- Evaluating information
- Working co-operatively

Materials
- *BC Science 9* textbook

Mitosis and meiosis are two methods of cell reproduction. These two cell division methods have different purposes. Body cells divide by mitosis so that each of the two daughter cells receives a full set of chromosomes. Sex cells divide by meiosis with the result that each of the four cells produced receives half the number of chromosomes. In this activity, you will use your knowledge of mitosis to help further your understanding about the events in meiosis.

Question
How are the processes of mitosis and meiosis similar and how are they different?

Procedure
1. Work with a partner. Study the diagram shown here, which shows the events of meiosis. Carefully compare this diagram to Figure 5.8 of mitosis and the description of cytokinesis on pages 156 to 158. Compare the activities of the chromosomes, nucleus, and cell membrane at each stage.



Meiosis I
Prophase I
Homologous chromosomes pair up, and non-sister chromatids exchange genetic material. This process is called crossing over.

Metaphase I
Homologous chromosomes pair up at the equator.

Anaphase I
Homologous chromosomes separate and are pulled to opposite poles by the spindle fibres.

Telophase I
One chromosome from each homologous pair is at each pole of the cell.

Interkinesis
Interkinesis is the stage between cell divisions. During this time, the cell will grow and make proteins as in interphase of mitosis. Unlike interphase in mitosis, there is no replication of DNA during this stage.

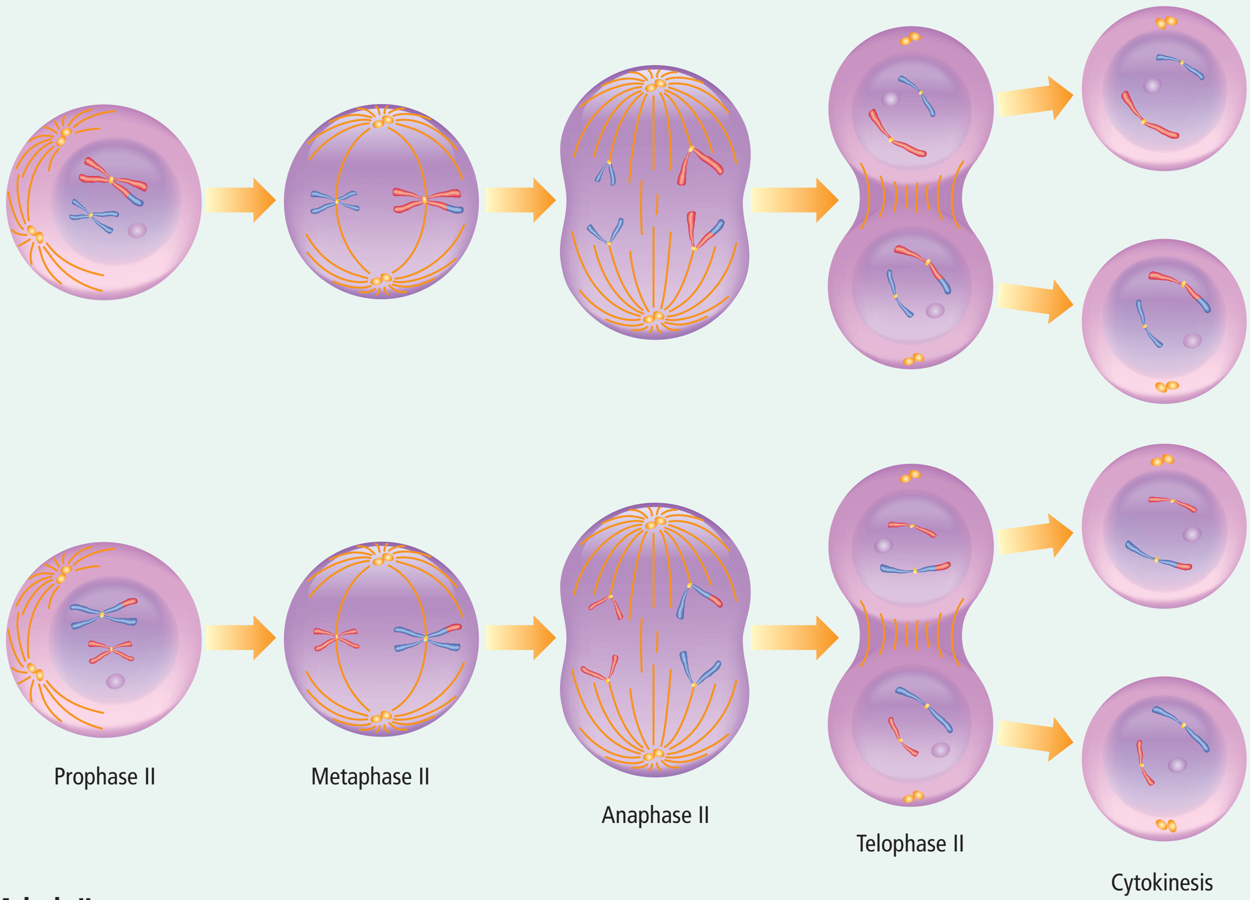
2. Your teacher will give you a chart in which you can compare meiosis I with mitosis. Write a brief description for each phase of meiosis I and mitosis in the chart.
3. Your teacher will give you a chart in which you can compare meiosis II with mitosis. Write a brief description for each phase of meiosis II and mitosis.
4. Compare your completed charts with another group's charts. Add any additional information to your charts.

Analyze

1. Is meiosis I or meiosis II more similar to mitosis? Explain.
2. List three similarities between mitosis and meiosis.
3. List three differences between mitosis and meiosis.

Conclude and Apply

1. (a) In a paragraph, explain the differences between mitosis and meiosis.
   (b) Explain which method contributes to genetic variation and why.



Meiosis II

Prophase II
There is one chromosome of the homologous pair in each cell.

Metaphase II
The X-shaped chromosomes form a single line across the middle of the cell.

Anaphase II
Sister chromatids move to opposite poles of the cell. Once they separate, each sister chromatid is considered to be a chromosome.

Telophase II
Spindle fibres begin to disappear, and a nuclear membrane forms around each set of chromosomes.

Cytokinesis
In cytokinesis, the two daughter cells are separated.

6-1D Modelling How Variation Occurs in Meiosis

SkillCheck

- Predicting
- Communicating
- Modelling
- Working co-operatively

Safety

- Be careful. The pipe cleaner ends are sharp.
- Do not put the pipe cleaners near anyone's eyes.

Materials

- 2 pink pipe cleaners
- 2 blue pipe cleaners
- scissors
- 4 beads, which 2 pipe cleaners can fit through
- red or pink pencil crayon
- blue pencil crayon
- blank paper

Genetic diversity is necessary for survival of a species. The process of mitosis in asexual reproduction does not produce variation, but the process of meiosis in sexual reproduction does produce variation. Two important events that occur in meiosis are crossing over and independent assortment. In this activity, you will model both of these events.

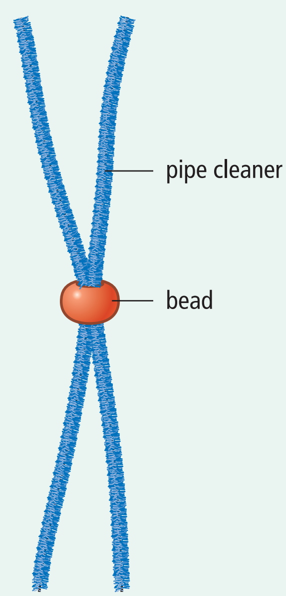
Question

How many different combinations can result from a single crossover in one pair of chromosomes?

Procedure

Part 1 Modelling Crossing Over

1. Cut a pink pipe cleaner $\frac{2}{3}$ of the way along its length.
2. Repeat this procedure for the other pink pipe cleaner and the two blue pipe cleaners.
3. Using two pipe cleaners the same length and colour, join the pipe cleaners in the middle by threading them through a bead (see the illustration below). The bead represents the centromere, and the two pipe cleaners represent the two chromatids of the chromosome. The pink chromosomes represent chromosomes that were inherited from the female parent. The blue chromosomes represent chromosomes inherited from the male parent.



Use a bead to join two pipe cleaners together.

4. Repeat step 3 for the remaining pipe cleaner pieces.
5. Pair up the pipe cleaners by length. The longer pink and blue pair represents one homologous pair of chromosomes, the shorter pair another homologous pair.
6. You will now model crossing over. The scissors represent an enzyme that cuts the chromosome. Use the scissors to cut one of the longer pink chromosomes 3 cm from its end. Cut a blue chromosome 3 cm from its end.
7. Attach the pink piece of chromosome to the shortened blue chromosome by twisting the wires together. Attach the blue piece of chromosome to the shortened pink chromosome by twisting the wires together. This models the action of enzymes reconnecting the pieces.
8. Copy the chart below in your notebook. Using your pink and blue pencil crayons, draw the chromosomes before and after crossing over occurs.

Appearance of Chromatids Before Crossing Over	Appearance of Chromatids After Crossing Over

Part 2 Modelling Independent Assortment

9. Draw a large circle on a blank piece of paper. Draw a dotted line across the diameter to represent the equator. Place the two pairs of homologous chromosomes from Part 1 at the equator as in metaphase I.
10. Model anaphase I by moving the homologous pairs apart toward opposite poles. On another sheet of paper, draw the two daughter cells that result, using pink and blue pencil crayons. Make sure you include the correct colours of the recombined chromosomes that resulted from crossing over.
11. Predict how many other different daughter cells are possible. Record your prediction.
12. Continue to model and draw all possible daughter cells that could result from the independent assortment of these two chromosome pairs.
13. Draw the possible gametes that could result following metaphase II.
14. Clean up and put away the equipment you have used.

Analyze

1. How many possible gametes could result from crossing over and the independent assortment of the two chromosome pairs?

Conclude and Apply

1. (a) Would crossing over between sister chromatids increase variation?
   (b) Explain why or why not.
2. How many possible gametes could result from crossing over and the independent assortment of the two chromosome pairs if crossing over had occurred in both chromosome pairs?

NATIONAL GEOGRAPHIC

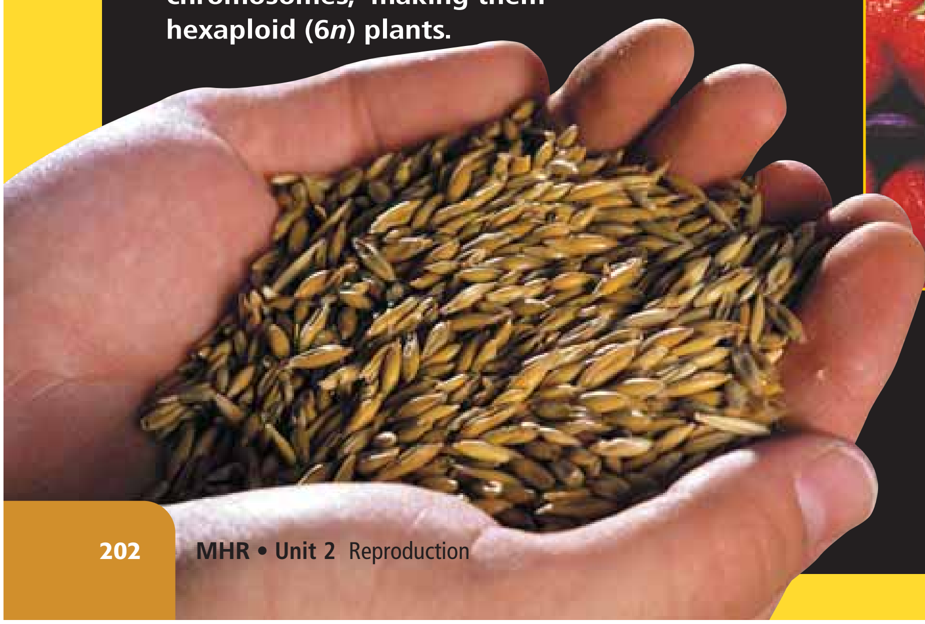
VISUALIZING POLYPLOIDY IN PLANTS

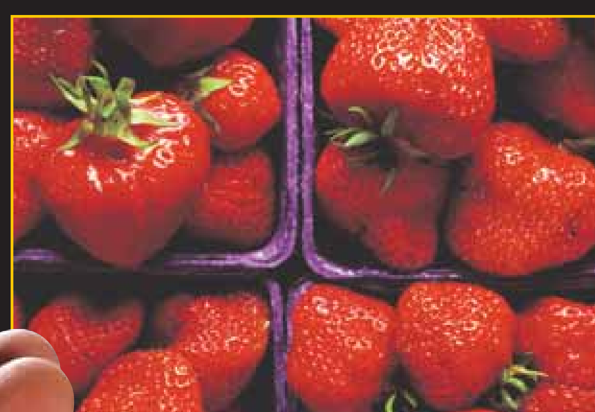
You received a haploid (*n*) set of chromosomes from each of your parents, making you a diploid (2*n*) organism. In nature, however, many plants are polyploid—they have three (3*n*), four (4*n*), or more sets of chromosomes. We depend on some of these plants for food.

TRIPLOID Bright yellow bananas typically come from triploid (3*n*) banana plants. Plants with an odd number of chromosome sets usually cannot reproduce sexually and have very small seeds or none at all.

TETRAPLOID Polyploidy occurs naturally in many plants—including peanuts and daylilies—due to mistakes in mitosis or meiosis.

HEXAPLOID Modern cultivated strains of oats have six sets of chromosomes, making them hexaploid (6*n*) plants.





OCTOPLOID Polyploid plants often are bigger than nonpolyploid plants and may have especially large leaves, flowers, or fruits. Strawberries are an example of octoploid (8*n*) plants.

Check Your Understanding

Checking Concepts

1. Compare the number of chromosomes in a human skin cell to the number of chromosomes in a human egg cell.
2. What characteristics could you use to identify a pair of homologous chromosomes?
3. What are the benefits of genetic diversity?
4. How does a zygote become an embryo?
5. Identify whether each of the following is an event in meiosis I or meiosis II.
   (a) Individual chromosomes move to the equator.
   (b) Homologous pairs of chromosomes move together to the equator.
   (c) Crossing over occurs.
   (d) Homologous chromosomes move to opposite poles.
   (e) Centromeres divide.
6. Copy the following table in your notebook. Complete the table comparing mitosis and meiosis.

Question	Mitosis	Meiosis
Where does it take place?		
How many cells are produced?		
What happens to the number of chromosomes?		
How do parent and daughter cells differ genetically?		
How do daughter cells compare to each other genetically?		

7. What is the difference between chromosomes in meiosis I and mitosis?
8. How does the number of chromosomes in metaphase of mitosis compare to the number of duplicated chromosomes in metaphase II of meiosis?
9. Explain how crossing over can result in variation.
10. Explain how independent assortment can result in variation.
11. Give an example of a chromosome mutation.
12. Give an example of a genetic disorder.

Understanding Key Ideas

13. Whole chromosomes can be lost or added during meiosis. Explain how this can occur.
14. Explain why meiosis is important for the survival of organisms.
15. Explain how you can tell whether a sperm cell is in meiosis I or meiosis II.
16. Draw a pair of homologous chromosomes before and after crossing over.
17. A dog has 76 chromosomes.
    (a) How many pairs of homologous chromosomes does it have?
    (b) How many chromosomes would be in each sperm cell of a dog?
18. What stage of the cell cycle would be best to use for karyotyping? Explain.

Pause and Reflect

Two types of twins can result from fertilization: identical twins and fraternal, non-identical twins. Identical twins result when one embryo splits in two. Such twins are genetically identical and look the same. However, their fingerprints will differ because fingerprints are caused by the movement of the fluid that surrounds the fetus as it grows inside the mother. As identical twins age, they will look less alike. What types of changes may occur that will make the twins less alike?