5

Reproduction and Development

Unit Preview

In this Unit, you will discover

- how cells grow and multiply
- how humans develop before birth
- how new reproductive technologies affect science and society

Unit Contents

A significant difference between living and non-living things is that living things are able to reproduce. Reproduction depends on the basic unit of life — the cell. The man on the right was once the size of the tiny baby he is holding. Each of them was once no more than a single cell. Their growth and development involves cellular processes in which body cells "reproduce," or divide to make identical copies of themselves.

Human reproduction involves a series of processes, which take place at the molecular level, at the cellular level, and on a larger scale. Understanding the processes of human reproduction has lead to many new technologies. Scientists can fertilize an egg in glassware, freeze the sperm of a cancer patient before radiation therapy, use an injection to prevent conception, and check for abnormalities in a developing fetus. These technologies all have risks and benefits. Because they are related to human life, they are also often highly controversial. As new technologies are developed, society must continually weigh the benefits and risks.

In this unit you will learn how body cells grow and divide and how sexual cells are produced. You will learn about male and female human reproductive systems and trace the development of a human.

These cells are an embryo produced by in vitro fertilization and maturation. What ethical issues are involved with this technology?

CHAPTER 14

Cellular Reproduction

Reflecting Questions

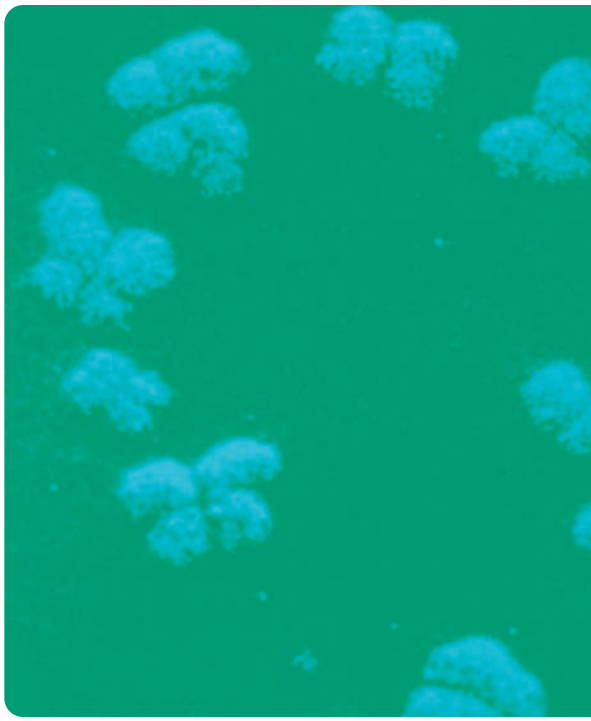
- What is the function of mitosis?
- What is the function of meiosis?
- What are the similarities and differences between eggs and sperm?

What is responsible for your eye colour, a crab's hard shell, the scent of a rose, or a cheetah's spotted fur? The answer to this question lies in the cells of each of these organisms. Cells contain genetic information, or genes, which form the basis for the inheritance of traits. Genes are passed from one cell to the next through a process of cell division. However, do all cells contain the same genes? Does a human skin cell contain the same genes as a human brain cell? Do both sperm and egg cells contain the same genes?

Research into the mechanisms of cell division has become more and more intricate with the advancement of technology. Some of the research has lead to technology that is undeniably beneficial. For example, research into the mechanisms of cell division has helped researchers develop treatments for cancer that are more effective and have fewer side effects than previous treatments. Some discoveries, however, have created ethical dilemmas that weigh heavily on the minds of many people. For example, based on today's understanding of cell division, researchers are now able to clone animals. Cloning humans and parts of humans is now within the realm of possibility. Although the technology has many potential beneficial applications, many people also see ways the technology could be abused. Others question the ethics of the cloning process altogether. We are faced with two challenges: thinking about the implications of new discoveries, and solving these ethical dilemmas in ways that will help both present and future populations.

New cells are produced throughout your life. This is necessary for growth, maintenance, and repair of your body. In this chapter, you will explore the processes by which cells reproduce and how genetic information is transmitted from cell to cell. In addition, you will discover how sex cells, sperm and eggs, are produced.

Chromosomes within the nucleus of a cell contain genetic information. How is this information transmitted from one cell to another?



Chapter Contents

14.1 How Body Cells Reproduce

OUTCOMES

- **Describe, in detail, the events of mitosis and cytokinesis.**
- **Use prepared slides of animal and plant cells to observe, identify, and describe the events of the cell cycle, including interphase, chromosome behaviour during mitosis, and cytokinesis.**

Recently, researchers in Pennsylvania discovered that a chemical compound in raw garlic can affect how certain body cells reproduce. Preliminary studies show that this compound, diallyl disulfide, can slow the rate at which cancer cells multiply. Somehow diallyl disulfide reduces the growth of a cancerous tumour. The key to understanding how such chemical compounds can affect cells lies in knowing how cells reproduce. Figure 14.1 shows two balls of cells, frog embryos, that are in the early stage of development. How are body cells produced? Do all body cells form the same way?

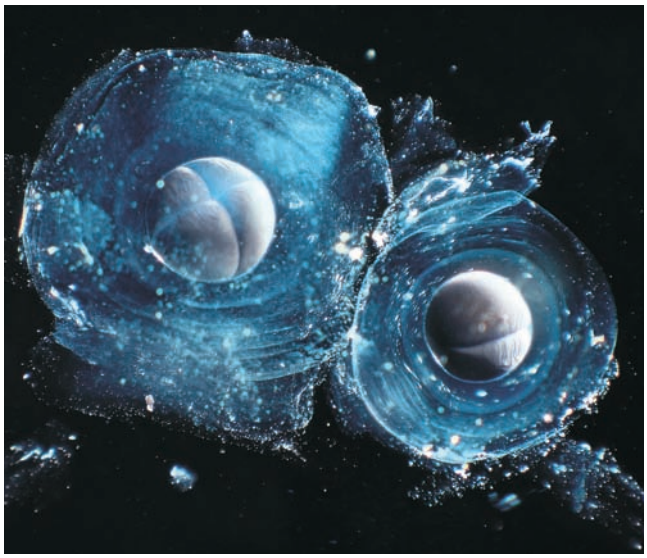


Figure 14.1 The number of cells in these frog embryos will double each time cell division takes place.

The Cell Cycle

Cells reproduce through a continuous sequence of growth and division known as the **cell cycle**. The cell cycle consists of two main stages, the growth stage and the division stage (as shown in Figure 14.2). In the growth stage, called **interphase**, the cell makes new molecules, which increases the cell's volume and mass. DNA (deoxyribonucleic acid), the molecule that forms the genetic blueprint of the cell, is copied during interphase in a process known as DNA replication. You will learn more about the process of DNA replication in Chapter 6.

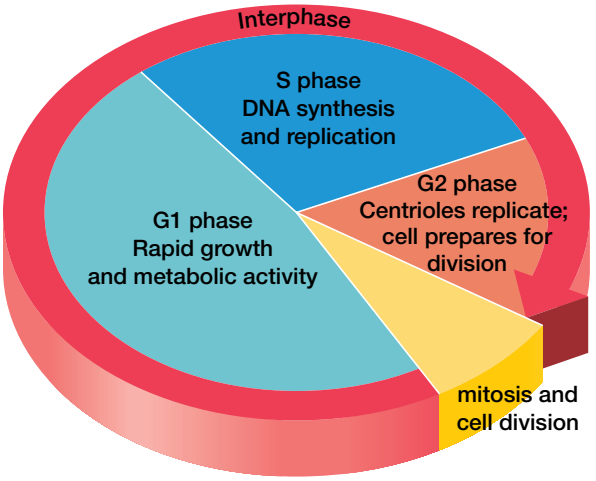


Figure 14.2 The cell cycle. Interphase is the growth stage, and mitosis and cytokinesis are the division stage.

During the first part of interphase, called gap 1 (G1), cells are carrying out metabolic activities to prepare for cell division. DNA is replicated during the S phase of the cell cycle. Scientists are very interested in what stimulates a cell to progress from G1 to S phase.

Cells that progress through the S phase then enter the last segment of interphase, called gap 2 (G2). During the G2 phase, cells are preparing to undergo division. The division stage involves two processes: **mitosis** (division of the nucleus) and **cytokinesis** (division of the cytoplasm). These two processes are the shortest events in the cycle of a cell. Cell division involves division of the cytoplasm of the cell to form two new cells.

BIO FACT

Some cells, such as neurons, do not divide. They do not go through G1 because they do not need to grow large enough to eventually form two cells. Non-dividing cells occupy a stage that some cell biologists call G0.

How does the cell cycle vary among different kinds of cells? The timing of the cell cycle and the lengths of the different phases depend on the type of cell and its environment. Study Figure 14.3, which shows the cell cycle for two different types of cells. What can you infer about the roles of each of these cells? Think about the different kinds of cells that make up the body of a bird, for example. Some cells are skin cells while others may be bone, muscle, or organ cells. Why might the cycle of some kinds of cells be faster than the cycle of others?

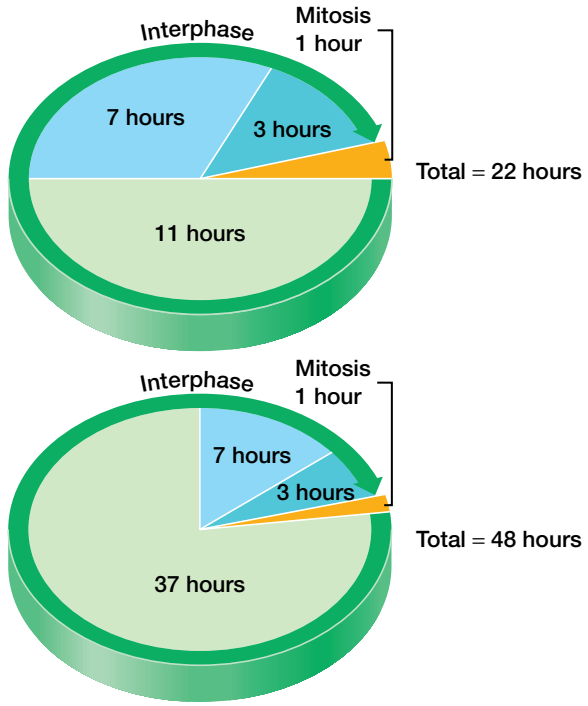


Figure 14.3 Different types of cells spend different relative lengths of time in the phases of the cell cycle.

What is the Function of Mitosis?

The giant pumpkin shown in Figure 14.4 has a mass of several hundred kg. It began life as a single cell and is now made up of billions of cells. How did the pumpkin grow so large? In order for an organism to grow, repair, and maintain its functions, new cells are needed. Each cell that undergoes mitosis will divide to produce two new cells. As mitosis and cell division occur, the pumpkin grows and the number of cells increases throughout the fruit. Through the process of mitosis and cell division, organisms can also regenerate damaged tissues. Every time you cut your finger, mitosis and cell division form new skin cells over the injured area. In certain cases, some organisms can regenerate entire body parts that have been lost. For example, when a starfish loses an arm as a result of an attack by a predator, a new arm is regenerated through the process of mitosis and cell division (see Figure 14.5). Mitosis and cell division are also necessary for maintenance of the body. Some cells need to be replaced because they cannot function properly. Others are replaced when they die. For instance, in the average person, millions of red blood cells die every day. These are replaced by new blood cells that are formed through mitosis and cell division.

BIO FACT

The life span of a cell in the lining of the stomach wall is only two days. The life span of a brain cell is 30–50 years.

Figure 14.4 This pumpkin required only four months to grow to this enormous size.

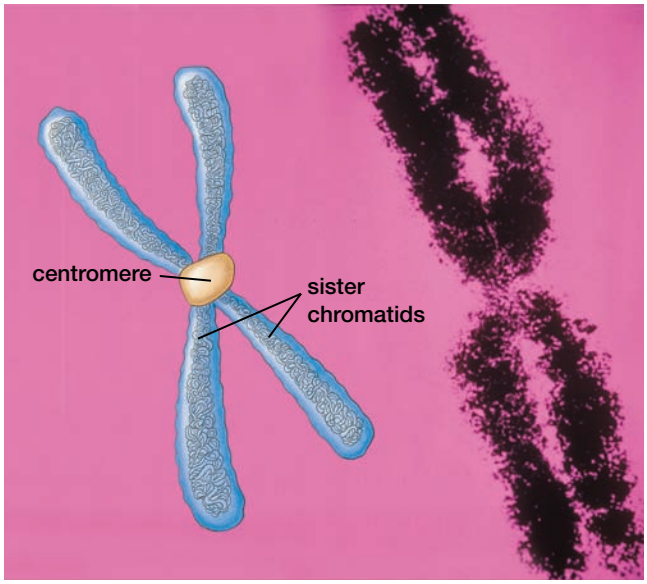
Figure 14.5 This starfish lost three arms. It was able to regenerate them through the process of mitosis and cell division.

BIO FACT

Researchers at the University of Wisconsin-Madison have discovered a strain of skin cells that live forever. The immortal skin cells could be used to treat burn patients and to serve as models for human skin disease research.

Mitosis and cell division occur in many somatic (body) cells. New cells that are produced for growth or repair are identical to the previously existing cells. For example, if skin cells are damaged, they are replaced with new skin cells — not cells of a different kind. The instructions that tell each cell how to perform its specific task and how to form new cells are stored in the DNA in the nucleus. During interphase, the DNA binds certain proteins and is in the form of very fine threads called **chromatin**. During the S phase, this DNA is replicated.

Why is a copy of DNA necessary in a cell? How is this information passed from one cell to the next? You will consider these questions in the Thinking Lab on page 463.



Magnification: 97 875x

Figure 14.6 A chromosome is made up of two sister chromatids that are joined by a centromere. This chromosome is ready to undergo mitosis.

The function of mitosis is to maintain the same number of chromosomes from cell to cell. During cell division, the original or **parent cell** divides to produce two new **daughter cells**. Mitosis ensures that each daughter cell contains the same number of chromosomes and the same genetic information as the parent cell. A body cell contains two copies of every chromosome. During mitosis, a parent somatic cell produces two identical daughter cells. Each human somatic cell has 46 chromosomes (two copies of each chromosome). Before mitosis, the parent cell has 46 chromosomes. After mitosis, the resulting two new daughter cells also each have 46 chromosomes. This is important because each new cell must have a complete set of genetic instructions to maintain itself and to produce new cells.

WORD LINK

The word "somatic" comes from the Greek word *soma*, meaning body.

The Phases of Mitosis

Several events must occur during mitosis to maintain the same number of chromosomes from parent cell to daughter cells. These events, or phases, can be observed most easily in the rapidly growing areas of plant and animal tissues. For example, the root tip is an area of the onion that grows rapidly and therefore contains cells that undergo mitosis frequently. At any given time, many onion root tip cells are in different phases of mitosis. Although these phases are continuous, for convenience they are divided into four main phases ordered according to the sequence in which they occur. The phases are called prophase, metaphase, anaphase, and telophase. Each phase is characterized by a particular arrangement of the chromosomes within the cell and by the appearance or disappearance of other cell structures. Refer to Figure 14.7 on page 464 to help you understand the various phases of mitosis.

Prophase

Mitosis begins with the first of the four stages called **prophase** (Figure 14.7). During prophase, the chromatin coils and supercoils forming thick, condensed **chromosomes**. Figure 14.6 shows a typical chromosome in a body cell. Each chromosome is made up of two **sister chromatids**, which are held together by a **centromere**. Sister chromatids are genetic copies of each other; that is, the DNA in one sister chromatid is identical to the DNA in the other. Because there is a copy of each chromosome (two chromatids), it is possible for each of the daughter cells to receive a full set of the parent cell's genes. If this copying had not occurred, each of the daughter cells would get only half of the parent cell's genes when the chromosomes divide in mitosis.

Other structures in the cell are also changing during prophase. The nuclear membrane and the nucleolus disappear. Centrioles made up of microtubules migrate to opposite poles of the cell. Spindle fibres, also made of microtubules, start to form between the two centrioles. These changes prepare the cell for the second phase of mitosis.

Metaphase

The second phase of mitosis is called **metaphase** (Figure 14.7). During metaphase, the spindle fibres attach to the centromere of the replicated chromosomes. The chromatids are guided by the spindle fibres to the middle of the cell, also known as the cell's equator. A spindle fibre from one pole is attached to one chromatid and a spindle fibre from the opposite pole is attached to the other chromatid at the centromere. Each chromatid has its own spindle fibre attachment in order to ensure that each new daughter cell will contain one of each of the chromatids (and therefore the same genetic information).

THINKING LAB

How Does Mitosis Work to Generate New Cells?

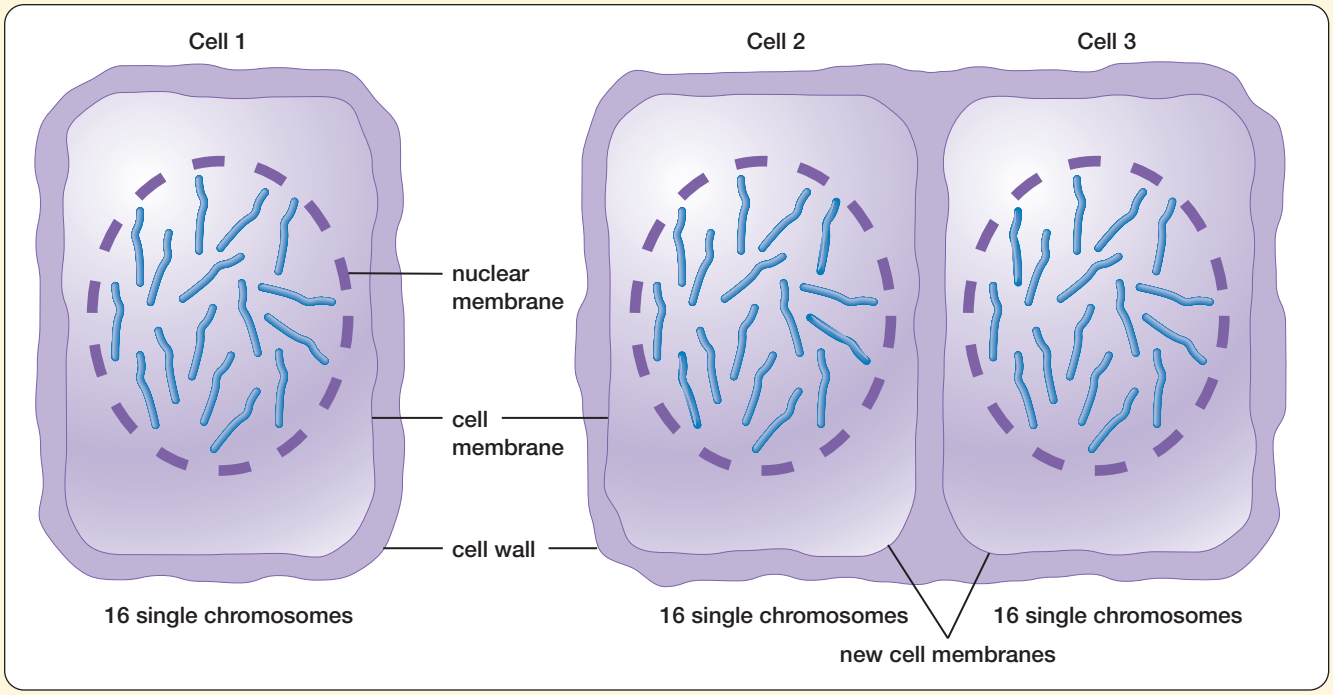
Background

These diagrams show onion root tip cells before and after mitosis. The onion root tip cell at the beginning of mitosis has 16 duplicated chromosomes, each consisting of two chromatids. The two daughter cells at the end of mitosis also have 16 chromosomes each. (Note that a chromatid is half of a duplicated chromosome. After chromatids separate into different cells, they are called chromosomes again.)

You Try It

Study the diagrams of the onion root tip cells shown. Compare the number of chromosomes in cell 1 with the number of chromosomes in cells 2 and 3, and answer the following questions.

1. What do you notice about the number of chromosomes in cells 1, 2, and 3? How is it possible to start with 16 chromosomes in cell 1 and end with 16 chromosomes in each of cell 2 and cell 3? Explain briefly.
2. What do you notice about the characteristics of each chromosome in cells 1, 2, and 3?
3. Do you think there are other cellular structures (that are not visible using the light microscope) involved in the process that takes the chromosomes from cell 1 and divides them between cell 2 and cell 3? If so, hypothesize their role in mitosis.
4. Predict each change in chromosome arrangement that would occur between the original cell 1 and the two new cells 2 and 3. Draw at least five individual cells to illustrate these changes. (Hint: If cell 2 and cell 3 contain the same genetic information, how will the chromosomes have to be arranged to be equally divided between cell 2 and cell 3?)



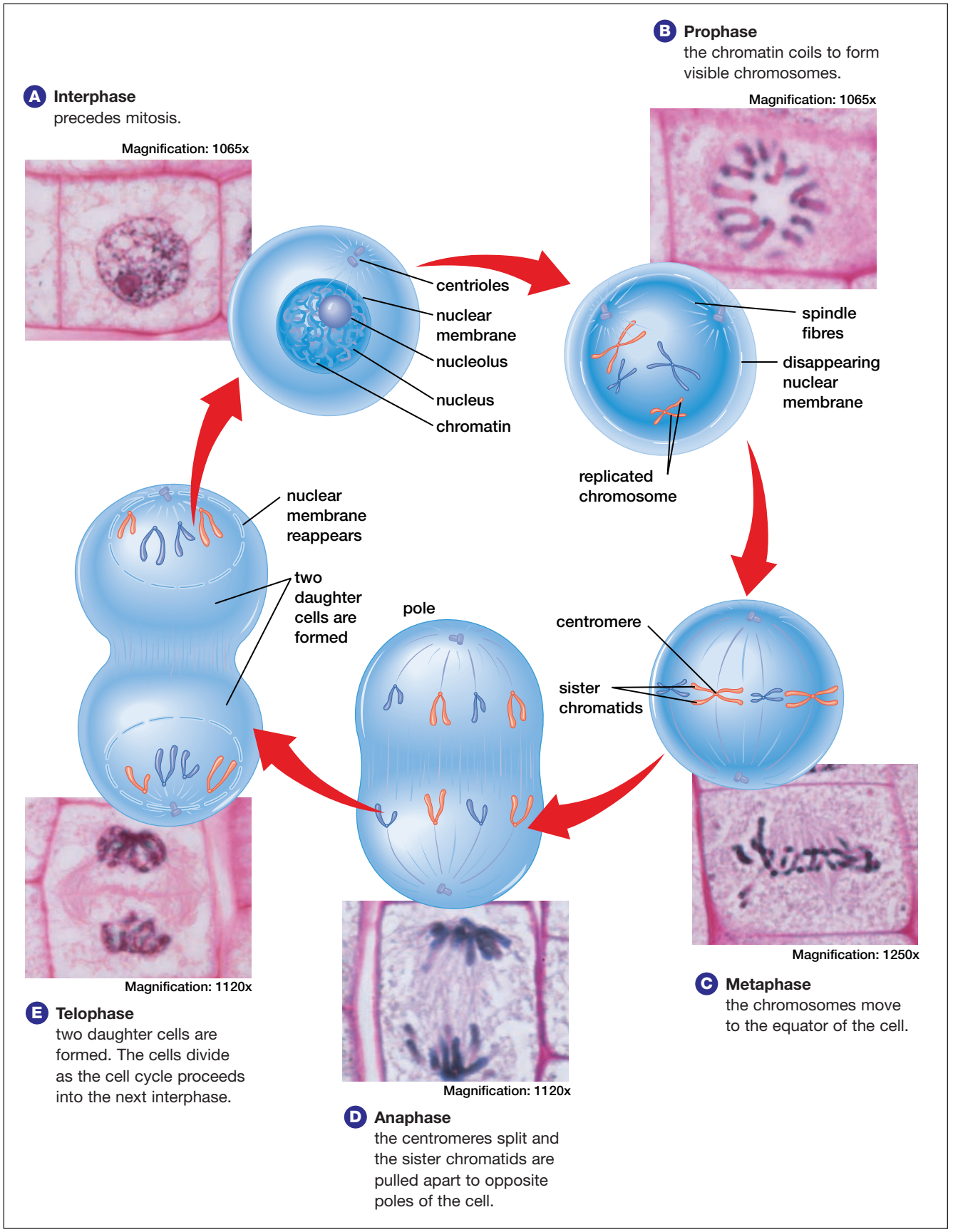


Figure 14.7 Phases of mitosis. The diagrams illustrate mitosis in animal cells. The photographs show mitosis in plant cells.

Anaphase

The third phase of mitosis is called **anaphase** (Figure 14.7). During anaphase, the centromere splits apart and the chromatids are pulled to opposite poles of the cell by the spindle fibres. The chromatids are pulled apart as a result of the shortening of the microtubules that make up the spindle fibres.

Telophase

The fourth and last phase of mitosis is called **telophase** (Figure 14.7). Telophase begins when the chromatids have reached the two opposite poles within the cell. At this time, each of the chromatids is called a single, non-replicated chromosome. The chromosomes now begin to unwind and become less visible. The spindle fibres are no longer needed, so they break down and disappear. The nucleolus reappears. A nuclear membrane forms around each new set of chromosomes, which are located at the opposite poles of the cell.

Cytokinesis

The separation of the cytoplasm and the formation of two new daughter cells is called cytokinesis. During cytokinesis, the cytoplasm (and all of its contents) divides between the two halves of the cell. In animal cells, an indentation of the membrane surrounding the two daughter cells forms and deepens, as shown in Figure 14.8. In plant cells, a cell wall and membrane form and separate the two newly formed nuclei, as shown in Figure 14.9. After cytokinesis is complete, two new daughter cells have been formed. In the next investigation, you will observe and draw the stages of mitosis in prepared slides of onion root cells and whitefish embryo cells.

WEB LINK

www.mcgrawhill.ca/links/atlbiology

To see an animation of the process of mitosis and cell division, go to the web site above, and click on **Electronic Learning Partner**. This can help you if you are having difficulty visualizing the different stages of mitosis.

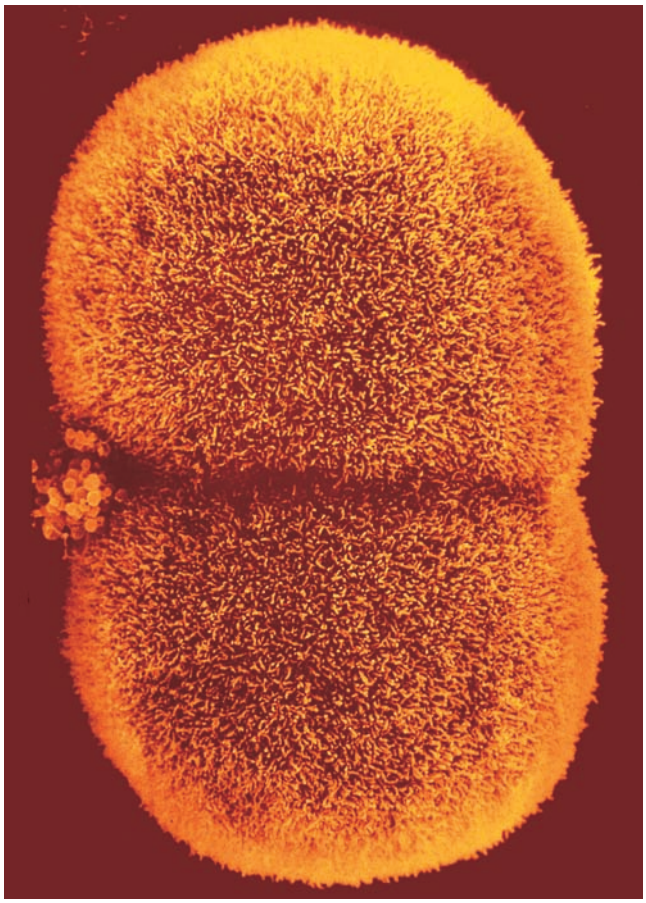


Figure 14.8 This animal cell is undergoing cytokinesis. The cell pinches inward to divide the cytoplasm equally between the two daughter cells.

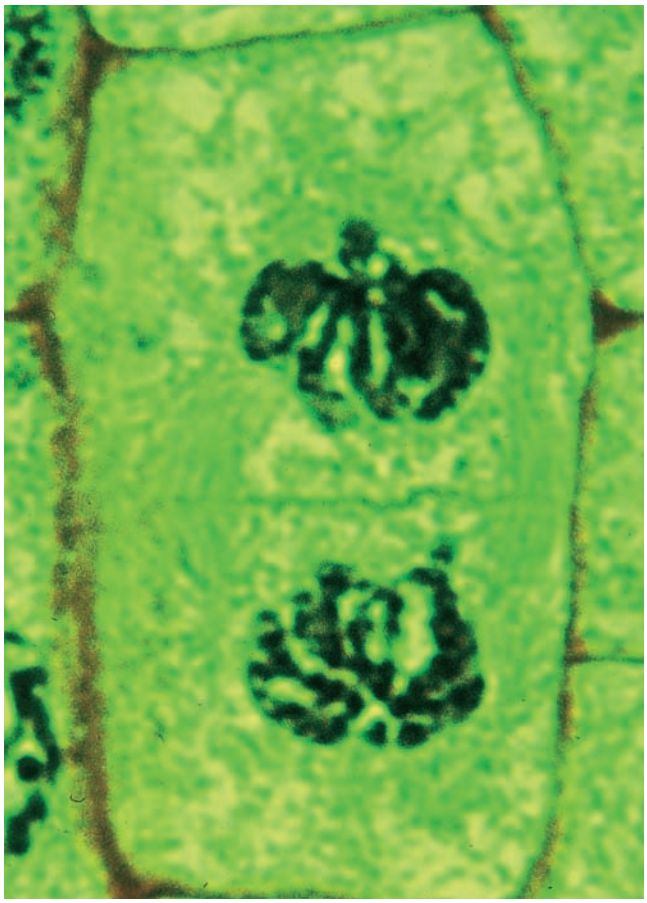


Figure 14.9 Daughter cells in plants are separated by a cell wall.

Investigation 14 • A

SKILL FOCUS

- Performing and recording
- Analyzing and interpreting
- Communicating results

Observing the Cell Cycle in Plant and Animal Cells

Using a microscope, it is possible to identify cells undergoing different stages of the cell cycle. In this investigation, you will observe and compare the stages of the cell cycle in onion tip cells and whitefish embryo cells.

Pre-Lab Questions

- What are the differences between plant and animal cells?
- How might these differences affect the stages of mitosis?

Problem

Are there any differences between the way plant and animal cells divide?

Safety Precautions

- Be sure your hands are dry when you plug in or disconnect the cord of the microscope.
- Handle the microscope slides carefully, so that they do not break or cause cuts or scratches.

Prediction

Are there any differences between mitosis in plant and animal cells? If you think there are, predict the ways in which you will observe differences.

Materials

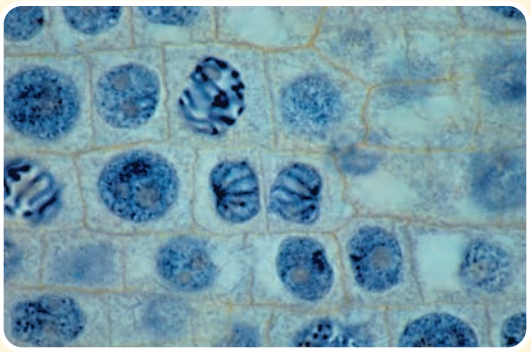
microscope
prepared slide of an onion root tip
prepared slide of a whitefish embryo

Procedure

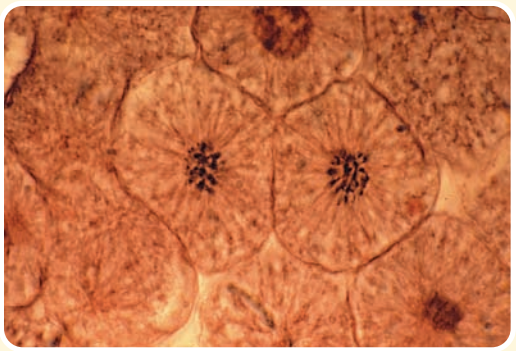
1. Place the onion root tip slide on the microscope stage and observe it under low power. Focus on the area just behind the tip of the root.
2. Carefully change to medium power, focus, and go to high power to observe the cells. As you look at each cell, determine which phase of mitosis it is in. Try to find cells in each phase of mitosis and draw a cell in each phase. Include cells in interphase and cells that are undergoing cytokinesis. Refer to the photographs in Figure 14.7 on page 464 to help you identify what you are observing.
3. Return to low power and move the slide to view the root tip. Change to medium power, focus, and go to high power. Note any differences from the last area you observed.
4. Change back to low power and remove the onion root tip slide. Place the whitefish embryo slide on the stage and observe it under low power.
5. Find an area of dividing cells. Change to medium power, focus, and go to high power. As you look at each cell, determine which of the stages of mitosis it is in. Refer to the photographs on this page to help you. Draw one cell from each of the stages. Note any differences between mitosis in animal cells and mitosis in plant cells.
6. Change back to low power and remove the slide.

Post-Lab Questions

1. Describe any differences you noticed in the cells behind the root tip, compared to those in the tip.
2. What other parts of an onion plant might be used to study mitosis?
3. What processes are occurring during interphase?



onion root tip cells, 330x



whitefish embryo cells, 320x

Conclude and Apply

4. What differences did you notice between the onion root tip cells and the whitefish embryo cells that were dividing in:
   (a) the size of the cells
   (b) the shape of the cells
   (c) the chromosomes in the cells

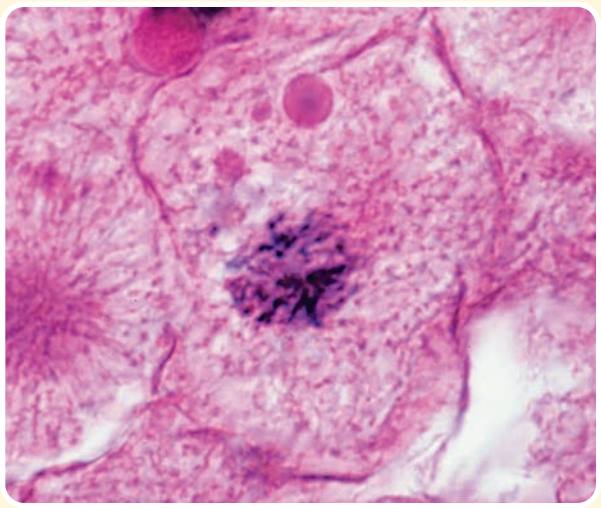
Exploring Further

5. Design an investigation to observe the chromosomes of a garlic root tip during cell division. You will need to consider the following points:
   - What kind of rapidly growing plant can be propagated easily in the laboratory?
   - What part of the plant will you use?
   - How will you organize and communicate your findings?

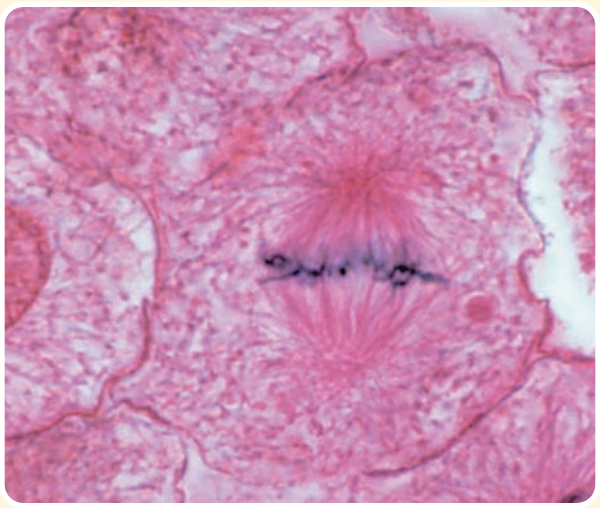
   You will need to prepare the garlic root tips for observation by making a *squash*. Making a squash involves soaking the tips in a mixture of stain and dilute hydrochloric acid, breaking up the tips with a needle, and then transferring the material to a slide. Your teacher will provide more specific guidelines to be used in your classroom.

   Once you have designed your investigation, get it approved by your teacher. Then carry out your procedure. In your report, compare your findings with the observations you made about onion root tip cells.

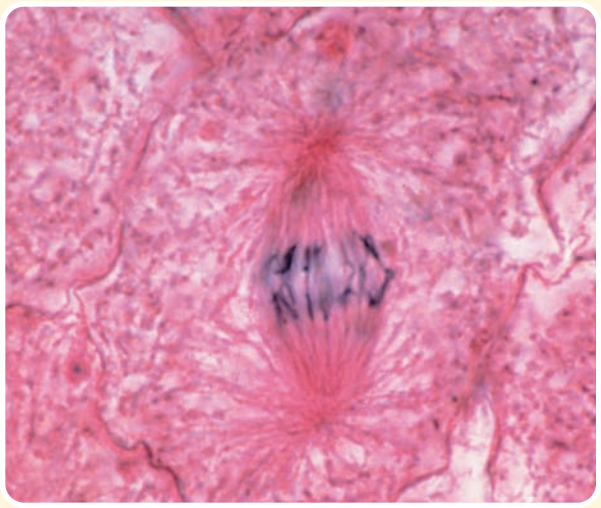
6. How long does it take to complete each phase of mitosis? From your prepared slide of onion root tip cells, select 30 cells at random and identify the phase in each. Determine the number of cells in each phase and present your findings as a ratio. Which phase requires the most time to complete? Which phase requires the least? Suggest possible explanations for your answers.



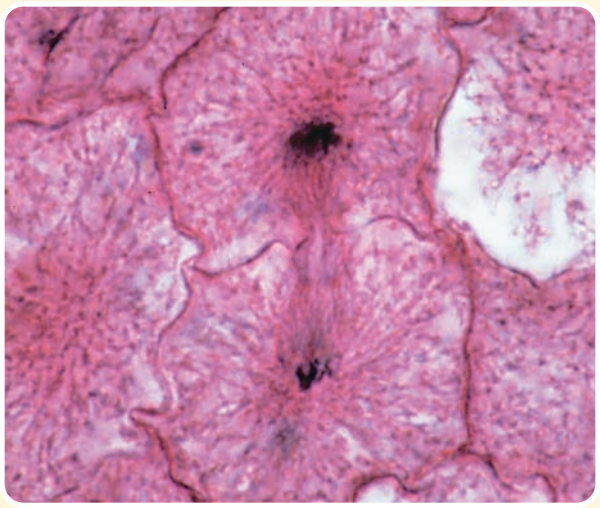
prophase in a typical animal cell



metaphase in a typical animal cell



anaphase in a typical animal cell



telophase in a typical animal cell

Mutations Affecting Cell Division

A **mutation** is a permanent change in the DNA molecule that can change the genetic information of a gene, causing the gene to function improperly or not at all. Mutations can be caused by certain chemical compounds, radiation, or specific viruses. Mutations can also occur spontaneously when DNA is replicating. After a mutation has occurred, it will be copied in any subsequent cell division and passed on to the daughter cells. This mutation will only be found in daughter cells produced from the parent cell that contained the mutation. Therefore, the mutation is found in a localized group of cells rather than in every cell in the body.

Most mutations in somatic cells are inconsequential because, even if they prevent the cell from functioning properly, the cell can simply be replaced by other normal cells. However, if a mutation occurs in a gene that controls the cell division process, it can result in cancer — the uncontrolled, rapid growth and division of cells. For example, toxic compounds found in cigarette smoke can cause a change in a gene known as FHIT on chromosome number three in humans. In the lungs, cells containing the mutated form of the FHIT gene undergo cell division much more frequently than normal lung cells. This rapid growth results in a mass of cells called a tumour, shown in Figure 14.10.

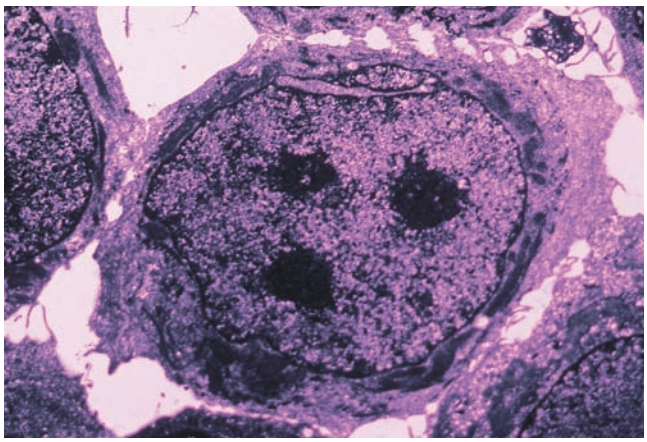


Figure 14.10 This photomicrograph shows cell division in a cancerous tumour. What is unusual about this cell?

Certain genes work like switches to regulate the rate of mitosis. If these genes are altered by a mutation, the rate of mitosis will also be affected. For example, once a cell has completed its cell cycle, certain genes are "switched on," or activated. These genes produce proteins that stop the process of mitosis. When these genes are "switched off," or inactivated, mitosis can continue and the cell can divide to produce new cells. A mutation could permanently inactivate these genes. As a result, the cell could begin to divide uncontrollably.

The rate of mitosis can also be regulated through genes that start cell division. A mutation could cause these genes to be "switched on" permanently, which would cause uncontrolled cell division. Genes that, when mutated, can cause cancer are called **oncogenes**. For example, retinoblastoma is a retinal cancer that is either inherited or results from a mutation to both copies of the retinoblastoma gene. This mutation results in the formation of a tumour on the retina of the eye.

Radiation Therapy and Chemotherapy

Because cancer cells divide more quickly than most other cells in the body, anything that interferes with cell division will harm cancer cells more than it will harm most healthy cells. Cancer treatments such as radiation therapy and chemotherapy are based on this idea.

Radiation therapy involves directing radiation, such as X-rays or gamma rays, at the affected part of the body. Patients usually receive doses of radiation several times a week. In internal radiation therapy, radioactive material is actually placed inside the body, next to the cancerous growth. In general, radiation therapy works by damaging the chromosomes in a cell, rendering it unable to grow or divide. Healthy cells are damaged as well as cancerous cells, but in many cases the healthy tissue is able to repair itself. The goal in radiation therapy is to focus the radiation on the diseased part of the body and avoid affecting healthy tissues and organs. Therefore, physicians tend to use radiation therapy on localized cancerous tumours including tumours of the skin, breast, larynx, and cervix.

Chemotherapy may include a course of one or several types of drugs, depending on the patient and the cancer. It may be used in conjunction with radiation therapy, or on its own. Some of the drugs attack dividing cells as they divide, while others prevent cells from dividing. Because chemotherapy affects the entire body, it is often used to treat cancers that are spread throughout the body, such as leukemia. Unfortunately, the drugs also affect healthy cells.

Both chemotherapy and radiation therapy can have numerous side effects. For radiation therapy, these include skin inflammation and fatigue. More

specific side effects depend on the location of the treatment. For example, radiation to the brain can cause hair loss. Radiation for testicular cancer in men can cause sterility. Chemotherapy often comes with side effects such as hair loss, nausea, or diarrhea. For both treatments, many of the side effects last only for the duration of the treatment, but some, such as sterility, can be permanent. The treatments are particularly harmful to healthy, normal cells that divide quickly, such as bone marrow cells, skin cells, hair cells, cells in the GI tract, and cells of the reproductive system.

Despite the potential severity of the side effects, most patients decide that the cancer itself is a greater risk than undergoing treatment. When physicians decide which cancer treatment or treatments to use, they try to strike a balance between the effectively killing cancer cells and minimizing the damage to healthy cells.

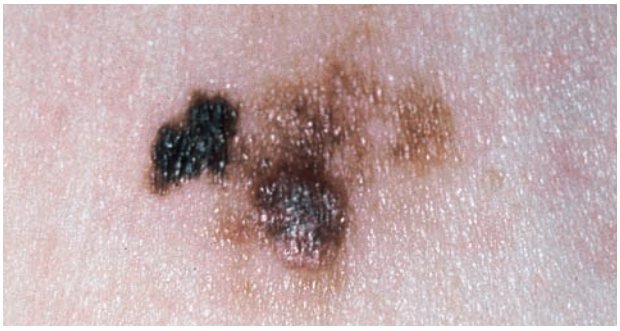
The ultimate goal of cancer research is to find a treatment that affects only cancerous cells, leaving healthy cells unharmed. The research is expensive, but because cancer is such a common and devastating disease, many people want to contribute to the research efforts. For most people, the best way to do this is by helping to raise money. Terry Fox, shown in Figure 14.11, was a pioneer of large-scale fundraising efforts for cancer research.

In April of 1980, Terry Fox, who had lost his leg to cancer, dipped his artificial leg in the Atlantic Ocean. His plan was to run across Canada to raise money for cancer research. Beginning on the island of Newfoundland, he ran over 5300 km to Thunder Bay, Ontario, where he was forced to stop because the cancer had spread to his lungs. He died shortly afterward. His legacy continues, however, and each year, Terry Fox runs are held in over 50 countries to raise money for cancer research. Fundraising efforts under Terry's name have raised $300 million worldwide. His influence, however, spreads even farther: the idea has caught on, and many groups now organize large-scale runs and other events as fundraisers for research.

Figure 14.11 Terry Fox raised $24 million for cancer research before his death in June of 1981.

SECTION REVIEW

1. What is the purpose of mitosis?
2. Explain why the DNA that makes up two sister chromatids is identical.
3. How can mutations lead to changes in the cell cycle?



4. A person notices a dark spot on their skin. This dark spot turns out to be skin cancer. What could have caused the start of the skin cancer tumour and how was mitosis and cell division of these cells affected?
5. How would a cure for skin cancer possibly work to stop the occurrence of skin tumours?
6. Summarize each phase of mitosis. Use sketches to illustrate your explanations.
7. In what areas of a plant would mitosis occur most frequently? Explain why.
8. At what time of year would mitosis in a plant occur most frequently? Explain why.
9. What would happen to the chromosome number in a cell if that cell does not go through S phase of the cell cycle?
10. Why is the process of cytokinesis necessary to ensure the normal functioning of a cell?
11. Explain why different kinds of cells in the body might live for different lengths of time.
12. Cancerous cells require less time to complete a cell cycle than do normal cells of the same kind. (The time required to complete interphase and prophase is substantially shortened). What is the importance of these observations? Develop one hypothesis that a scientist might test if they were looking to control cancer.

14.2 How Reproductive Cells Are Produced

OUTCOMES

- Describe, in detail, the events of meiosis.
- Explain the necessity of chromosome reduction during the production of sex cells.
- Identify examples of technologies that were developed based on the understanding of cell division, including cloning and stem cell research.
- Examine the processes of spermatogenesis and oogenesis.
- Describe and compare the structure of sperm and egg cells.

Look around you at the diversity of individuals in your neighbourhood, classroom, or home. Other than identical twins, every individual in the world is unique (see Figure 14.12). Diversity exists between sisters, brothers, and even between you and your parents. Diversity is not limited to people, however — all species of organisms show diversity.

Figure 14.12 Every person receives characteristics from both their parents.

What is the Function of Meiosis?

From earlier studies, you learned that reproduction involves the union of two cells to form a zygote (see Figure 14.13). The zygote contains chromosomes from both parents, but it does not contain double the number of chromosomes found in a normal body cell. How is this possible? The answer lies in a process called **meiosis**. Meiosis is a special type of cell division that occurs only in reproductive organs. Meiosis produces reproductive cells called gametes. The gametes, either eggs or sperm, are **haploid** (n), which means they contain only one copy of each type of chromosome that the **diploid** (2n) parent cell contains.

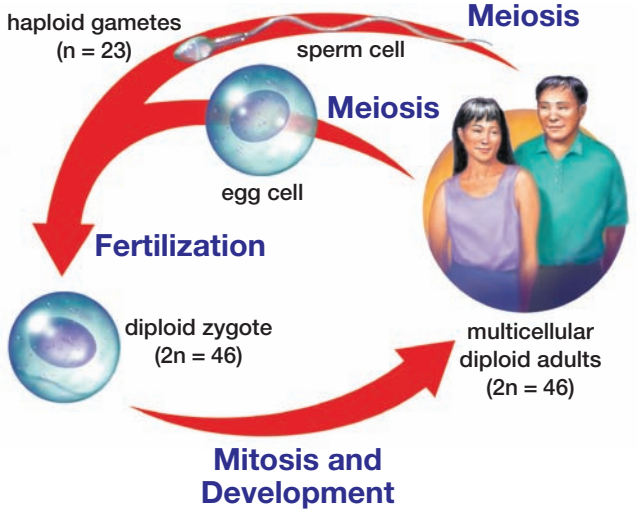


Figure 14.13 The human life cycle

WORD LINK

The word "meiosis" comes from the Greek word *meion*, which means to diminish.

The first part of meiosis reduces the chromosome number from diploid to haploid. This is often referred to as **reduction division**. For example, human sperm cells contain n = 23 chromosomes compared to the 2n = 46 chromosomes found in all somatic cells. Each human sperm or egg cell contains 22 **autosomes** and one **sex chromosome** (either an X or a Y chromosome). Autosomes are chromosomes that are not directly involved in

determining the sex of an individual. Females have two X chromosomes and males have one X and one Y chromosome. Table 14.1 shows the number of chromosomes for a variety of organisms. What do you notice about the diploid number of chromosomes for each organism?

Table 14.1
Chromosome numbers of some common organisms

Organism	Diploid body cell (2n)	Haploid gamete (n)
Fruit fly	8	4
Garden pea	14	7
Corn	20	10
Tomato	24	12
Leopard frog	26	13
Apple	34	17
Human	46	23
Chimpanzee	48	24
Dog	78	39
Adder's tongue fern	1260	630

Phases of Meiosis

Study Figure 14.14 on the next page, which shows the phases of meiosis. Meiosis involves a sequence of phases that is similar to mitosis: prophase, metaphase, anaphase, and telophase. However, meiosis involves two sequences of these phases, called meiosis I and meiosis II. Select a pair of chromosomes to follow through each phase of meiosis. In your notebook, describe briefly what is happening during each phase. How are the chromosomes arranged in each phase? Use your knowledge of mitosis to describe what events must have occurred to create the different chromosomal arrangements from one phase to the next. How many cells are produced at the end of meiosis II? After you have completed your notes, read the following sections describing the details of each phase of meiosis.

Interphase

Recall that in mitosis, the chromosomes replicate during interphase before cell division begins. This also occurs before meiosis I begins. During replication, the chromosomes are not condensed and are not easily visible. After replication, each chromosome is made up of a pair of identical sister chromatids. The sister chromatids are joined together by a centromere.

Prophase I

In prophase I, each pair of chromosomes that carry the same genes, called **homologous chromosomes**, become aligned. The homologous pairs are called **tetrads**. The term "tetrad" is from the Greek word *tetra* meaning four. Where does each member of a homologous pair come from? Each diploid cell has two copies of each chromosome. One copy of the chromosome pair was "donated" by the female gamete (egg), and the other copy of the chromosome was "donated" by the male gamete (sperm). During fertilization, the union of gametes forms a diploid zygote. All the cells in your body contain copies of chromosomes of this original diploid zygote. Therefore, each cell has one copy of each of your mother's chromosomes (maternal origin) and one copy of each of your father's chromosomes (paternal origin).

Like a pair of shoes, homologous chromosomes are similar to each other but they are not identical. The chromosomes are homologous because they are made up of the same genes. However, although homologous chromosomes contain the same genes, they may have different forms of these genes, called **alleles**. Alleles determine the way in which the gene is expressed.

During the pairing process, **crossing over** of chromatids can occur, in which **non-sister chromatids** exchange segments of chromosomes, as shown in Figure 14.15 on page 473. Each segment contains hundreds or even thousands of genes. This allows for the recombination of genes in each chromosome and contributes greatly to genetic variation. As a result of crossing over, individual chromosomes contain some genes from maternal origin and some genes from paternal origin. Without crossing over, every chromosome would either have only a maternal or paternal origin. You will model crossing over in the next Thinking Lab.

WEB LINK

www.mcgrawwhill.ca/links/atlbiology
To see an animation of the phases of meiosis and crossing over, go to the web site above, and click on **Electronic Learning Partner**. This can help you if you are having difficulty visualizing the different stages of meiosis.

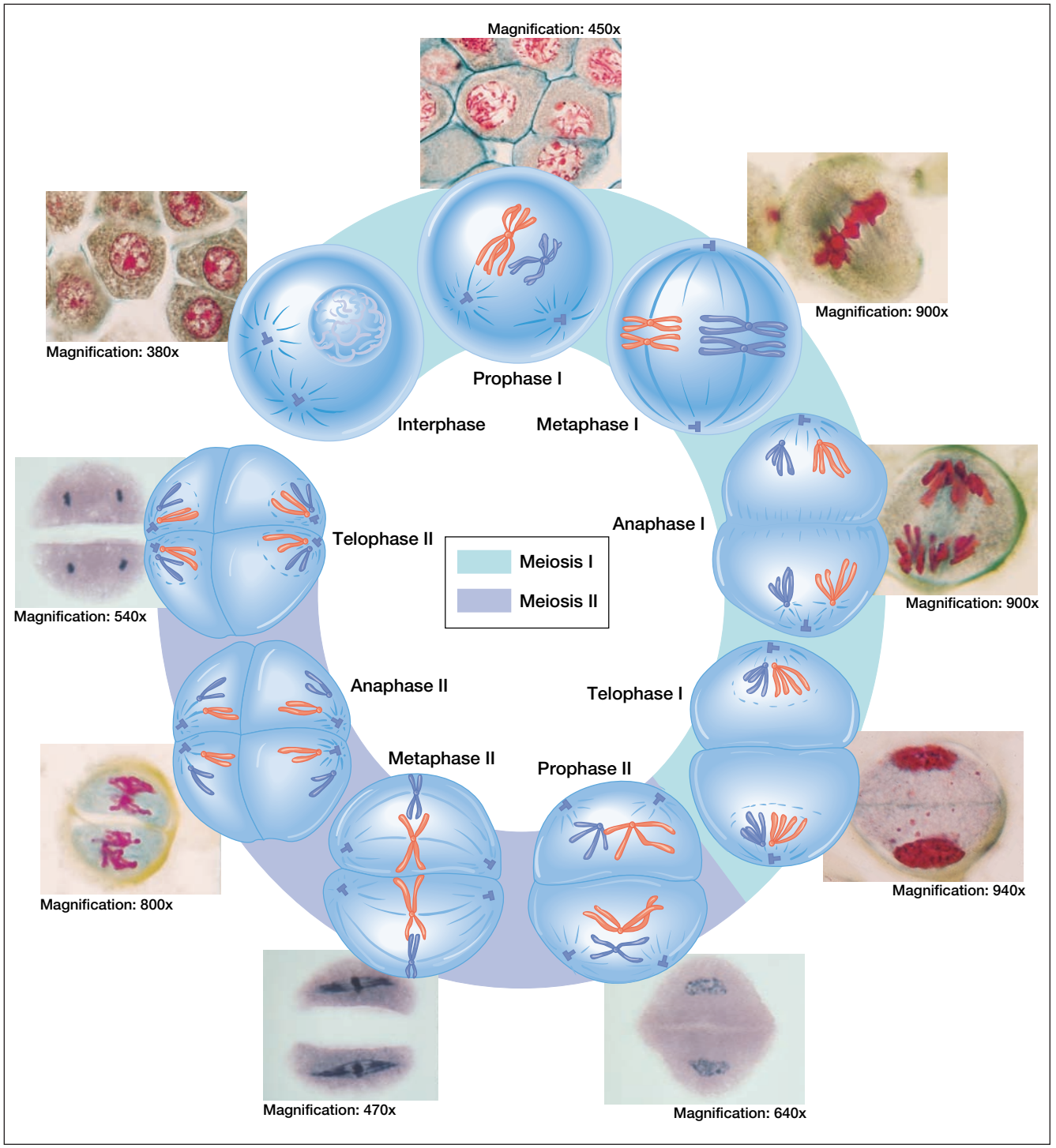


Figure 14.14 Phases of meiosis

Metaphase I

Following prophase I, a spindle fibre attaches to the centromere of each chromosome. A spindle fibre from one pole attaches to one pair of sister chromatids, and a spindle fibre from the opposite pole attaches to the other pair of sister chromatids in the tetrad. The spindle fibres pull each tetrad to the equator of the cell. However, the chromosomes do not line up in single file as they do in mitosis. Instead, they line up in their homologous pairs. In each pair, one homologous chromosome is positioned on one side of the cell's equator, and the other homologous chromosome is positioned on the other side of the cell's equator. It is important to note that chromosomes that come from one parent are not all positioned on the same side of the cell's equator. Rather, they are positioned randomly so that some sister chromatids of maternal origin face one pole while other sister chromatids of maternal origin face the other pole of the cell.

Anaphase I

During anaphase I, the homologous chromosomes separate and move to opposite poles of the cell. They are pulled apart by the shortening of the spindle fibres. Notice that the centromere does not split (as it does in mitosis), and that the sister chromatids are held together. Thus, only one chromosome from each pair will move to each pole of the cell.

Telophase I

Telophase I does not occur in all cells. Where telophase I does not occur, cell division goes directly to meiosis II. If telophase does occur, the homologous chromosomes begin to uncoil and the spindle fibres disappear. The cytoplasm is divided, the nuclear membrane forms around each group of homologous chromosomes, and two cells are formed. Each of these new cells contains one copy of each chromosome. Because each chromosome already consists of two chromatids, a second chromosome replication does not take place between telophase I and prophase II of meiosis. In females, meiosis II occurs after the egg is fertilized by a sperm cell.

At the end of telophase I, each cell contains some maternal chromosomes and some paternal chromosomes, due to the independent assortment of chromosomes during metaphase I. Each cell also contains chromosomes that are made up of a combination of maternal and paternal alleles as a result of crossing over during prophase I. You will illustrate these processes and their outcomes in the MiniLab on page 475.

Meiosis II

The phases of meiosis II are identical to mitosis. The two cells from telophase I go through prophase II, metaphase II, anaphase II, and telophase II. Each cell beginning meiosis II is haploid but consists of replicated chromosomes (each consisting of two chromatids). At the end of meiosis II, the daughter cells are still haploid but each cell contains single unreplicated chromosomes (no longer made up of two chromatids attached together). The daughter cells at the end of meiosis II will develop into gametes in animals and either gametes or spores in plants.

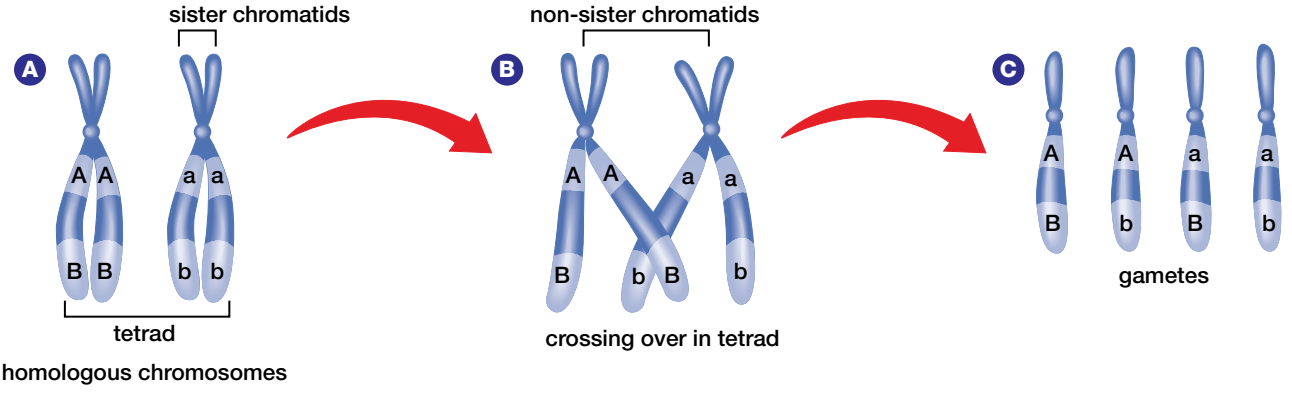


Figure 14.15 During prophase, homologous chromosomes form pairs (A). Non-sister chromatids wind around each other and exchange segments of chromosome (B). As a result, new genetic combinations are produced in gametes (C).

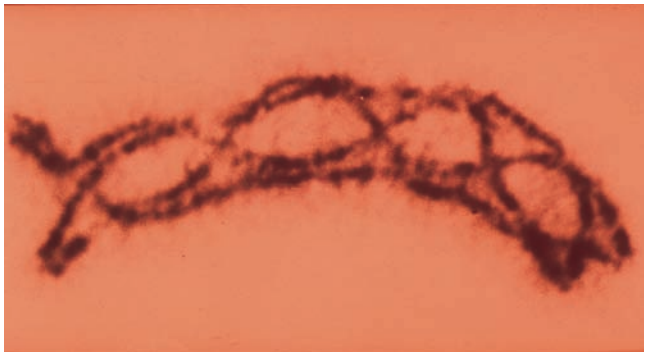


Figure 14.16 Crossing over may occur several times between non-sister chromatids.

Comparison of Meiosis with Mitosis

Now that you are familiar with meiosis and mitosis, what events characterize these two processes (refer to Figure 14.16)? Study Figure 14.17 and prepare a list of events, according to occurrence and process, which distinguish meiosis from mitosis. Which events occur in meiosis that do not occur in mitosis? Why is this so?

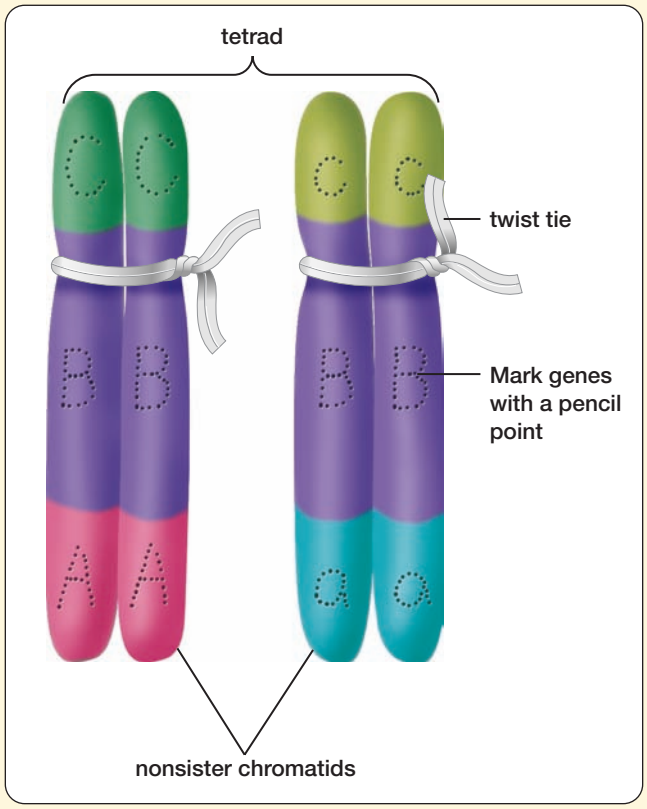
As you know, each diploid human female cell has two X chromosomes, and each diploid human male cell has one X chromosome and one Y chromosome. The Biology Magazine on page 476 outlines a theory about the origin of human sex chromosomes. What happens to these chromosomes during meiosis? What determines whether a human zygote will develop into a male or a female?

THINKING LAB

Modelling Crossing Over

Background

Crossing over occurs during prophase I of meiosis. During tetrad formation, non-sister chromatids cross over and exchange genes. This process creates new combinations of alleles in the resulting gametes. In this lab, you will use a simple model to simulate crossing over and record the possible outcomes.



You Try It

1. Make a copy of the data table shown below.
2. Arrange four strips of clay as shown in the illustration. These strips represent a pair of chromosomes after replication. Use different colours of clay to identify the different genes. Using a pencil point, indicate the presence of different alleles of specific genes by using capital and lower case letters as shown.
3. First, assume that no crossing over occurs. Model the appearance of the four gametes that will result at the end of meiosis. Record your model's appearance by drawing the gametes' chromosomes and their genes in your data table.
4. Repeat steps 2 and 3, this time assuming that crossing over occurs between genes B and C.
5. Compare any differences in the appearance of genes on chromosomes in gamete cells when crossing over occurs and when it does not occur. Wash your hands after handling the clay.
6. What would be accomplished if crossing over occurred between sister chromatids? Explain your answer.
7. Define "crossing over." How is this similar to shuffling a deck of cards? Explain your answer.

Appearance of gametes	
No crossing over	Crossing over

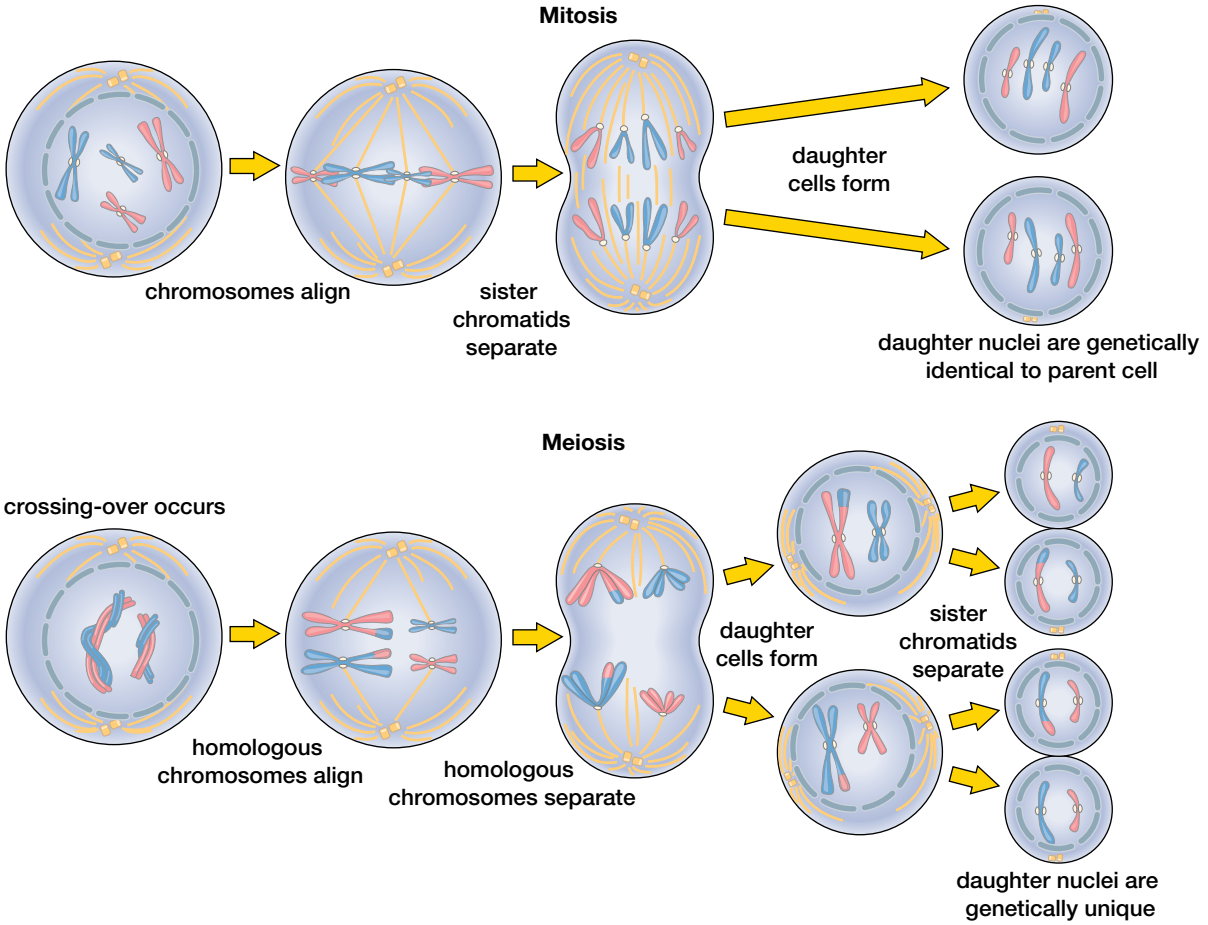


Figure 14.17 Meiosis compared to mitosis. The blue chromosomes were received from one parent and the red chromosomes were received from the other parent. Crossing over is shown in non-sister chromatids that are both red and blue.

MINI LAB

Meiosis I Flip Book

Create a flip-book for each of the steps of meiosis I given in the table shown here. Draw each step on plain 7.5 × 13 cm (3 × 5 in.) index cards. Position your drawing of the cell membrane in the same location on each card. Use different colours to represent chromosomes of maternal and paternal origin and to identify crossing over of non-sister chromatids. When the drawings are complete, tightly bind one end of the cards using an elastic band. Write the name of the phase on the card where that phase begins. By slowly flipping through the book, you can watch the chromosomes appear, double to form sister chromatids, form tetrads of homologous pairs, move to the cell's equator, separate to opposite poles, and become enclosed by nuclear membranes.

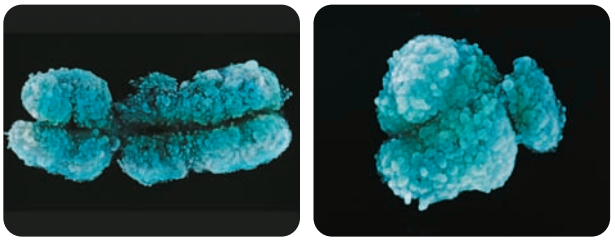
Analyze

1. Describe the appearance of the chromosomes in the two cells at the end of telophase I.
2. Are different combinations of chromosomes possible in the daughter cells? Explain your answer.

Steps of Meiosis I	Number of Cards
Original cell	1
Nuclear membrane disappears and sister chromatids form	3
Sister chromatids form homologous pairs (tetrad) and crossing over takes place	4
Centrioles move to the poles of the cell and spindle fibres appear	4
Homologous pairs line up on the cell's equator	2
Homologous pairs are pulled apart, randomly separating non-sister chromatids	3
Spindle fibres disappear and the nuclear membrane forms	3
Cytokinesis occurs forming two cells	3

The Origin of Human Sex Chromosomes

Among the characteristics that distinguish women from men, it is only one small chromosome that determines your sex. Of the 46 chromosomes in the human genome, 44 are autosomes and two are sex chromosomes, called X and Y. Women have two X chromosomes and men have one X and one Y chromosome. The Y chromosome is much smaller and contains only about 1% of the genes found in the X chromosome. Why is there such a huge difference in size between the two sex chromosomes?



Human female (left) and male sex chromosomes

From X to Y

Genetic scientists have proposed that millions of years ago, the sex chromosomes began as a normal pair of autosomes that were equal in size. However, during the course of human evolution, changes occurred in an X-like ancestor that caused it to become reduced in size. These changes involved mutations that rearranged the chromosome. For example, a small part of the chromosome may have broken away, rotated 180 degrees, and then reattached itself. This type of mutation is called a chromosomal inversion, and it results in a permanent genetic change. Various other factors can cause chromosomal mutations as well, including radiation, chemical compounds, and viruses. Changes in the structure of the X chromosome were important in determining sex in humans. During meiosis, homologous pairs of chromosomes are able to exchange genetic information through crossing over. This process recombines genes (a source of variation) in each chromosome and keeps the genetic information in both chromosomes similar. Mutations, such as inversions, prevent recombination from taking place because each chromosome no longer has the same genetic sequence. Genetic scientists believe that this process resulted in a reduction in size of one of the X chromosomes to its present Y condition.

How many chromosomal inversions were necessary for the Y chromosome to evolve to its present state? Recent work by American geneticists Bruce Lahn and David Page suggests that at least four inversions have taken place in the Y chromosome over the last 300 to 350 million years B.C.E. The researchers used 19 genes to reconstruct the history of changes in the Y chromosome. These are ancient genes that are still common to both the X and Y chromosome, and thus served as "fossils" to help identify past mutation events. The first chromosomal inversion occurred about 240 to 320 million years B.C.E. This marked the origin of the Y sex chromosome and happened at the time when mammals and birds evolved from reptiles. The second and third inversions took place from 80 to 170 million years B.C.E, resulting in greater dissimilarity between the chromosomes. The most recent inversion, about 50 million years B.C.E, occurred during primate evolution when monkeys evolved from their prosimian ancestors.

Are Sex Chromosomes Necessary?

Chromosomes are not always important in determining sex. For instance, many reptiles, including lizards, snakes, and turtles, do not have special sex chromosomes. So, what determines the sex of a snapping turtle? When a female snapping turtle lays her eggs, she buries them in sandy soil. The eggs incubate there until the young turtles hatch. If the temperature of the soil is 23–27°C, all the hatchling turtles will be male. If the temperature is cooler or warmer, they will be female. Temperature of the environment affects genes on certain chromosomes of the embryos. In turn, these genes cause the turtles to develop into either males or females. This systems works because reptiles are cold-blooded and development of the young occurs, in most cases, outside the body of the female.

In contrast, mammals have internal development. Their young develop at a constant temperature. This kind of reproduction requires a different method of determining sex. The development of a special Y chromosome allows sex to be determined without the effect of temperature. This is believed to be advantageous because species where the young develop inside the female often receive greater care and protection than those species' young that develop outside the body of the parent. This improves the chances of survival of offspring.

Follow-up

In most cases, an extra chromosome causes serious consequences in the development of an organism. For example, three copies of chromosome 21 in humans causes Down syndrome. However, females have two X chromosomes while males have only one. Do research to find out why the second set of genes carried on the "extra" X chromosome in females relative to males does not cause developmental problems in females.

Gamete Formation

The end result of meiosis is the production of gametes. This process, called **gametogenesis**, results in the production of sperm and eggs. The process of male gamete production in animals is called **spermatogenesis**. The process of female gamete production in animals is called **oogenesis**.

Spermatogenesis

Meiosis in mature males takes place in the testes, the male reproductive organs. Figure 14.18 shows the production of sperm, which starts with a diploid germ cell called a **spermatogonium**. This cell enlarges and undergoes meiosis I and meiosis II. The final product is four haploid sperm cells. Notice that each sperm cell has the same number of chromosomes and the same amount of cytoplasm. Following meiosis II, the sperm cells develop into mature sperm. Each cell loses cytoplasm and the nucleus forms into a head. As well, a long, tail-like flagellum is formed for locomotion. Spermatogenesis can occur throughout the year in some organisms, including humans. In other organisms, sperm production occurs only during a certain time of the year called a breeding season. For example, many species of migratory birds reproduce only during the spring and summer months.

Oogenesis

In females, meiosis takes place in the ovaries, the female reproductive organs. The process starts with a diploid germ cell called an **oogonium** (see Figure 14.18). This cell enlarges and undergoes meiosis I and meiosis II. At the end of meiosis I, the cytoplasm is not equally divided between the two daughter cells. The cell that receives most of the cytoplasm is called the primary oocyte. The other cell is called a polar body and is not a viable sex cell. As the primary oocyte undergoes meiosis II, the cytoplasm is again unequally divided. Only one cell becomes an egg, or ovum, and contains most of the cytoplasm. The other cell, a polar body, is not a viable sex cell. The purpose of the unequal division of the cytoplasm is to provide the ovum

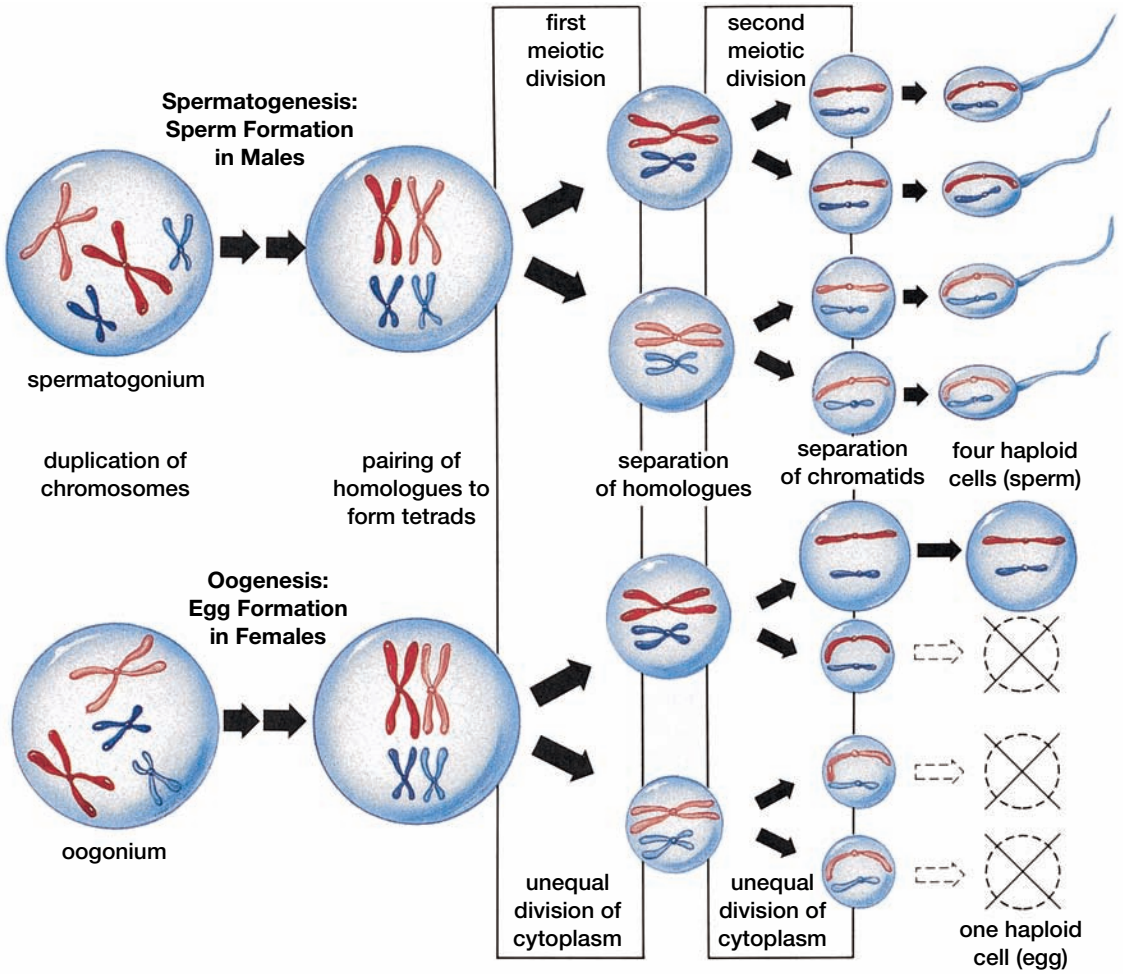


Figure 14.18 Production of sperm and eggs in animals. Which cells are diploid and which are haploid? Note that this diagram is not to scale.

with sufficient nutrients to support the developing zygote in the first few days following fertilization.

Meiosis I and meiosis II are not continuous in many organisms. In humans, for example, meiosis I begins in the ovarian tissue of the embryo before birth and does not continue beyond prophase I. The continuation of meiosis I occurs after the female reaches puberty. Normally, only one oogonium undergoes this process each month. Meiosis II takes place after fertilization by a sperm cell. The production of ova (two or more egg cells) in females continues from the start of puberty until menopause, which usually occurs between 40 and 50 years of age.

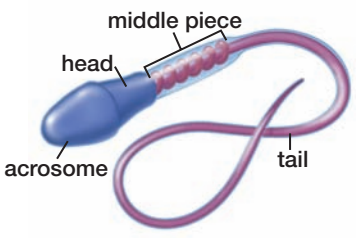
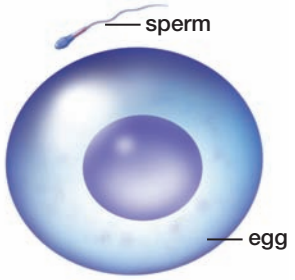
Sperm cells and egg cells are similar in that both are haploid cells formed by meiosis. As you know, they also differ in many ways. For example, all egg cells contain an X chromosome, while sperm cells may contain either an X or a Y chromosome. Sperm and egg cells differ in many other significant ways, some of which are listed below in Table 14.2.

Technologies Based on Cell Division

In this chapter, you have learned how cells divide and reproduce. Based on their understanding of how mitosis and meiosis, researchers have developed a number of technologies, many of them controversial. For example, animal cloning technologies involve bypassing the meiosis step of animal reproduction. Instead, the nucleus of an egg cell from a surrogate mother animal is removed. The diploid nucleus of a cell from the animal to be cloned is placed in the empty egg cell. The egg cell is then implanted into the surrogate mother's uterus. The cell divides and forms an embryo, which eventually develops into a new animal that is the exact copy of the animal that donated the nucleus of one of its cells. You will learn more about cloning in Chapter 18.

Stem cell technologies form another controversial area of research. The Biology Magazine on the following page discusses some of the issues surrounding the use of stem cells.

Table 14.2
Comparing Sperm Cells and Egg Cells

	Sperm Cell	Egg Cell
		
sizes	■ head: about 5 microns long ■ middle piece: about 5 microns long ■ tail: about 40 microns long	■ about 100 microns in diameter
energy reserves	■ before ejaculation: mitochondria process fat to provide energy ■ after ejaculation: mitochondria process fructose (a sugar) in seminal fluid to provide energy	■ an egg can only live about one day if it is not fertilized. If fertilized, an egg will implant in endometrium, which serves as an energy source
mitochondria	■ middle piece of sperm contains about 50–100 mitochondria, which supply ATP and provide energy for movement	■ cytoplasm of egg cell contains about 140 000 mitochondria
numbers produced	■ 300 to 500 million sperm; sperm are continuously produced	■ at puberty, an ovary contains 300 000 to 400 000 oogonia (follicles) ■ usually, one egg is released from the ovary each month
motility	■ motile: sperm have an undulating tail (flagellum) that enables the sperm to swim	■ not motile: eggs have no structure to propel themselves
outer structures	■ sperm head has a cap called an *acrosome*, which contains several enzymes that help the sperm enter an egg	■ egg is covered by a specialized outer coating that can, in most cases, be penetrated only by sperm of the same species ■ once one sperm has penetrated the egg, the egg's outer coating becomes impenetrable to other sperm

Stem Cells: A Medical Miracle?

Imagine doctors being able to grow new hearts and kidneys or new nerves for patients paralyzed by spinal cord injury. Stem cells could be the key to these kind of dramatic medical advances in the years to come.

What Are Stem Cells?

Stem cells have been described as the blank slate of the human body — undifferentiated (nonspecialized) cells that can give rise to any type of cell, from a nerve cell to a white blood cell. Until they differentiate, stem cells have the unique ability to reproduce themselves indefinitely.

Most of the rapidly dividing cells of a week-old embryo are stem cells. These differentiate to become all of the multitude of cell types in the body. People retain a limited number of stem cells — one for every five million other cells. To replace worn-out or damaged cells, the body uses reserves of stem cells. These are found primarily in bone marrow but also in the blood, muscle tissue, lining of the digestive tract, brain, and retina of the eye.

Where Do Researchers Get Stem Cells?

Doctors already take advantage of the rejuvenating power of stem cells to treat patients with some kinds of leukemia through bone marrow transplants. However, these transplants are extremely painful and must be done under general anesthetic, which entails its own risks. Through the use of drugs or growth factors, adult stem cells can also be encouraged to increase in the bone marrow and can then be collected directly from the blood.

Other sources of stem cells include aborted fetuses, unused embryos from in-vitro fertilization treatments, and cord blood. Cord blood is the blood left in the placenta and umbilical cord following a birth. Canada now has a well-established private cord blood bank in Toronto and a public one in Alberta, which accept donations.

What Issues Surround Stem Cell Research?

- The nature of the sources of stem cells has made it difficult to get enough human stem cells for research.
- Cloning of human embryos could provide a large supply of stem cells.
- A sick person's DNA could be transferred into a human egg. Stem cells from an embryo developed from the egg could be used to treat the sick person.
- A particular human being could be cloned.
- Harvesting the stem cells from an embryo destroys it.
- Moral, ethical, and legal questions arise around using human embryos.
- Potential uses for stem-cell therapies include treating cancers, strokes, hepatitis, spinal cord injuries, Alzheimer's disease, diabetes, heart disease, muscular dystrophy, AIDS, and other disorders.
- It once seemed that adult stem cells could only develop into a few types of tissue, but recent findings have shown that scientists may be able to program adult stem cells to act like embryonic stem cells.

What Discoveries Have Canadians Made?

- At least two types of adult stem cell exist: one that initiates the short-term replacement of tissue and the other that initiates the long-term replacement of tissue. (Hospital for Sick Children, Toronto, Ontario)
- In rats, stem cells from bone marrow injected into damaged heart muscle took on the appearance and function of heart muscle cells, replacing the damaged cells in 20 out of 22 trials. (McGill University Health Centre, Montréal, Québec)
- In the presence of an embryo protein (called sonic hedgehog), adult stem cells from bone marrow rapidly reproduce, much as stem cells do in a human embryo. (J.P. Robarts Research Institute, London, Ontario)

Stem cells hold the promise of releasing millions of people from pain and suffering or death. Stem cells also raise disturbing questions about how we view life.

Stem cells are stored in liquid nitrogen.

Follow-up

Debate with classmates the pro or con aspects of stem cell research. You may want to use the following real-life situation to help focus your discussion:

In the U.S., parents of a six-year-old girl with a rare inherited blood disease asked doctors for help in conceiving a baby that could provide donor stem cells for their daughter. They selected the most suitable embryo from among 15 created through in vitro fertilization. They had a little boy, and their daughter received stem cells from his cord blood in the hope that she will now produce healthy bone marrow.

In this section, you learned how male and female gametes are formed through meiosis. In Chapter 15, you will learn what happens once a human sperm has fertilized a human egg. You will trace the development of a human embryo from its beginnings as a few unspecialized cells to a fully formed fetus that can function and grow outside its mother's uterus. First, however, you will learn about the male and female reproductive systems and the hormones that regulate their function. You will also investigate reproductive technologies and the effects they have on society.

WEB LINK

www.mcgrawhill.ca/links/atlbiology

In Chapters 5 and 6 you learned about a wide variety of reproductive strategies for plants and animals, including budding, fragmentation, sexual reproduction, and parthenogenesis. In this chapter, you have seen how cell division is involved in sexual reproduction. Gametes are produced by meiosis, and then the resulting zygote divides by mitosis. How is cell division involved in other types of reproduction? Go back to Unit 2 and choose one reproductive strategy to investigate. Find out what happens on the cellular level for your chosen strategy. To begin your search, go to the web site above, and click on **Web Links**.

SECTION REVIEW

1. What is the purpose of meiosis?

2. Where does meiosis occur in organisms?

3. What are homologous pairs and why are they important?

4. What characteristics of an egg cell and a sperm cell are critical to their ultimate function of combining to form a zygote?

5. Compare and contrast each of the following pairs of terms.

(a) body cells and gametes

(b) haploid and diploid

(c) sperm and egg

6. Draw a consequences map linking the following terms, presented here in no particular order: *independent assortment*, *homologous chromosomes*, *crossing over*, *haploid*, *reduction division*, *tetrad*, *non-sister chromatids*, *diploid*. Briefly describe what is occurring at each step in your map. You may include sketches to accompany your descriptions.

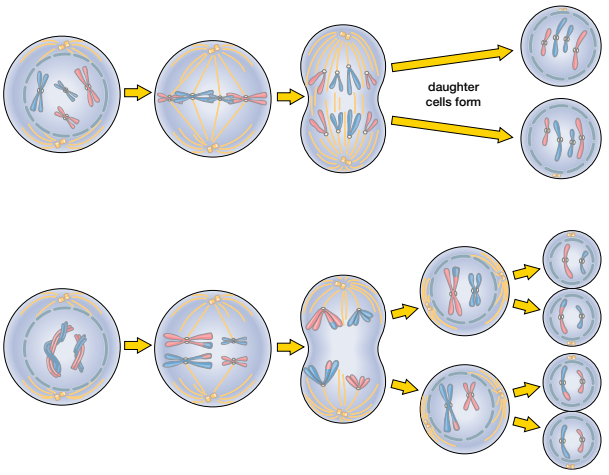
7. Which division in meiosis, I or II, is most similar to mitosis? Write a brief explanation.

8. Egg cells always contain an X chromosome, while sperm may contain either an X or a Y chromosome. Explain why this is the case.

9. During spermatogenesis, one spermatogonium forms four sperm. During oogenesis, however, only one viable egg is produced from one oogonium. Explain in detail why this is the case.

10. All organisms that reproduce sexually have even diploid numbers. Explain why, using an example.

11. Describe what is occuring in the two processes shown here. Copy the diagrams into your notebook and use proper labels to explain your answer.



Chapter Summary

Briefly explain each of the following points.

- Cells reproduce continually through a sequence known as the cell cycle. (14.1)
- The growth stage of the cell cycle is called interphase. (14.1)
- The division stage consists of mitosis and cell division. (14.1)
- Mitosis functions to produce new cells, allowing organisms to grow, repair, and maintain regular functions. (14.1)
- Mitosis consists of four stages: prophase, metaphase, anaphase, and telophase. (14.1)
- Meiosis is a type of cell division that occurs in reproductive organs. (14.2)
- Meiosis involves two sequences known as Meiosis I and Meiosis II. (14.2)
- Meiosis produces gametes: males produce sperm and females produce eggs. (14.2)
- Sperm and eggs are haploid cells that combine during fertilization to form a dipoid zygote. (14.2)
- Sperm and eggs have a number of differences in structure that relate to their function. (14.2)

Language of Biology

Write a sentence using each of the following words or terms. Use any six terms in a concept map to show your understanding of how they are related.

- cell cycle
- interphase
- mitosis
- cytokinesis
- chromatin
- parent cell
- daughter cell
- prophase
- chromosomes
- sister chromatids
- centromere
- metaphase
- anaphase
- telophase
- mutation
- oncogene
- meiosis
- haploid
- diploid
- reduction division
- autosomes
- sex chromosome
- homologous chromosomes
- tetrad
- allele
- crossing over
- non-sister chromatid
- gametogenesis
- spermatogenesis
- oogenesis
- spermatogonium
- oogonium

UNDERSTANDING CONCEPTS

1. Describe the three parts of interphase and their importance.

2. What role does mitosis play in the survival of an organism? What plant and animal tissues would be best to use to study the process of mitosis? Explain your answer.

3. What role does meiosis play in the survival of an organism? What plant and animal tissues would be best to use to study the process of meiosis? Explain your answer.

4. In what phase of the cell cycle does a cell spend most of the time? Explain your answer.

5. During what phase of the cell cycle does growth occur?

6. Why is meiosis often referred to as reduction division?

7. Draw a series of diagrams illustrating meiosis in a plant cell that has a chromosome number of $2n = 8$.

8. A plant can be reproduced using a clipping consisting of a stem and a few leaves. The clipping is placed in water until roots form from the stem. What process, mitosis or meiosis, is responsible for the reproduction of plants through clippings? Briefly explain your answer.

9. How would mitosis differ between a haploid and a diploid organism?

10. Compare cytokinesis in plant and animal cells.

11. Define and distinguish among chromatin, chromatids, and chromosomes.

12. Some cells do not divide.

(a) Give an example of a cell that does not divide.

(b) Do non-dividing cells go through any stages of interphase? Briefly explain your answer.

13. Explain why radiation therapy is suited to localized cancers such as cervical cancer, while chemotherapy must be used to treat cancers that spread throughout the body, such as leukemia.

14. An egg cell is much larger than a sperm cell. Explain why this is the case.

15. Explain the significance of the random orientation of sister chromatids in metaphase I.

16. Explain the importance of crossing over during prophase I of meiosis.

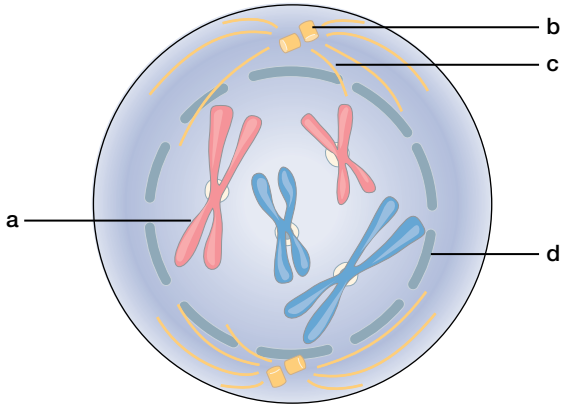
17. In what way is meiosis II similar to mitosis?

18. Explain how specific mutations can lead to cancer.

19. In your notebook, complete the following table comparing mitosis and meiosis.

	Mitosis	Meiosis
Occurs in	body cells	
Number of cells produced per parent cell	two	
Number of chromosomes in parent cell		diploid (2n)
Number of chromosomes in daughter cells	same as parent cell	
Type of cell produced		gametes
Function		

20. The diagram below shows a cell in early prophase of mitosis. In your notebook, recreate the diagram and label it.



21. Describe the location, number, and function of the mitochondria in a sperm cell.

22. Explain why sperm have tails, while eggs do not.

23. What kind of cell division (meiosis or mitosis) is involved with each of the following functions?

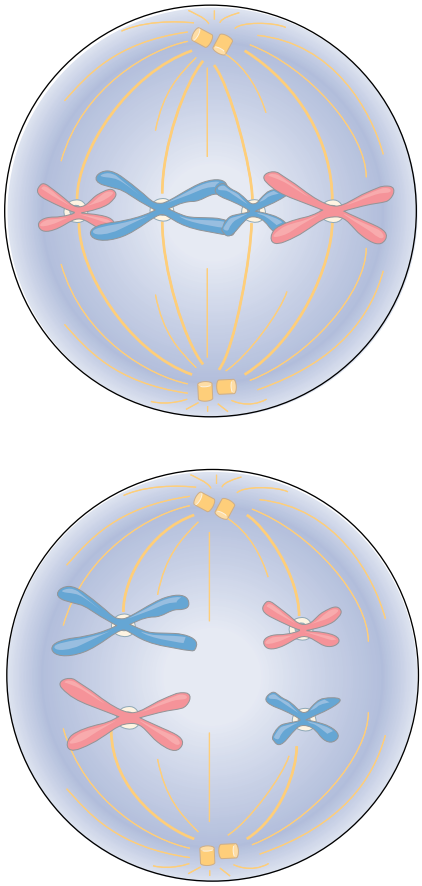
(a) tissue renewal

(b) growth of an embryo

(c) production of a gamete

24. Explain the role of autosomal chromosomes and of sex chromosomes.

25. One of the diagrams below represents metaphase I of meiosis? Which one is it? How do you know?



INQUIRY

26. A researcher wants to determine how much time cells found at the tips of grass stems spend in each phase of cell division relative to the other phases. Outline a detailed procedure that the researcher could follow in order to find this out. Include safety precautions and a materials list.

27. Does mitosis in humans occur more frequently in a five-year-old or an 85-year-old individual? Explain your answer. Many scientists are working on ways to slow the effects of aging. Given your answer to the first part of the question, suggest an area for further research. List three ways this research could be applied.

COMMUNICATING

28. In which cells in the human body does mitosis occur most frequently? Explain your answer.

29. In which cells in the human body does mitosis occur least frequently? Explain your answer.

30. Using the information provided in Table 14.1 (on page 471), draw a fruit fly cell undergoing mitosis and answer the following questions.

(a) How many chromatids would be found in a leopard frog body cell in prophase?

(b) How many chromosomes would be found in a dog sperm cell?

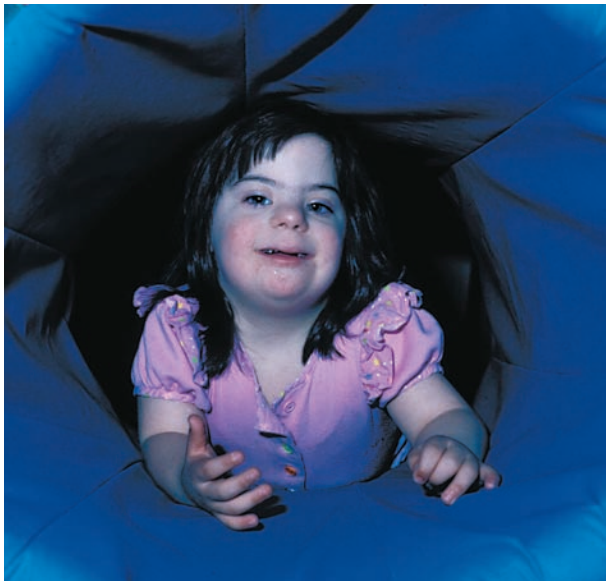
31. Explain how mitosis would be affected if DNA were prevented from replicating.

32. Create a chart to illustrate the number of chromosomes in the following list of cells before, during, and as a result of mitosis. A human cell with 46 chromosomes, a dog cell with 78 chromosomes, an apple cell with 34 chromosomes, and a corn cell with 20 chromosomes.

33. Create a chart to illustrate the number of chromosomes in the following list of cells before, during, and as a result of meiosis. A human cell with 46 chromosomes, a dog cell with 78 chromosomes, an apple cell with 34 chromosomes, and a corn cell with 20 chromosomes.

34. A particular chemotherapy prevents the formation of microtubules that form spindle fibres for mitosis. Explain in detail why and how this would affect cell division.

35. Trisomy is a condition that can be caused by an error in meiosis. In trisomy, body cells have one extra chromosome. Using a diploid cell that has $2n = 4$, show how an error in meiosis could produce a gamete that would lead to trisomy. (The photo shows a child with Down Syndrome. Trisomy 21 in humans is the cause of Down Syndrome.)



36. The technique used to determine the location of genes relative to one another on one chromosome is called chromosome mapping. This is possible, in part, because of crossing over, which affects how genes move together between non-sister chromatids. Use the Internet or print resources to find out more about how chromosome mapping is done. Present your findings in a brief report that answers the following questions.

- How do scientists measure the distance between genes?
- How does the distance between genes affect how they move from one chromatid to another during crossing over?
- Why is it important to know the position of a gene on a particular chromosome?

MAKING CONNECTIONS

37. Cancer is the second-leading cause of death in Canada after heart attacks. Are some types of cancer preventable? What kinds of things can people do to decrease their chance of getting cancer? Use Internet and print resources to answer these questions, and create an informative pamphlet to educate the public with your answers.

38. Stem cell research is an area of considerable controversy, particularly since it involves the use of human embryos. Read the Biology Magazine on page 479. Then use the Internet or print resources to find out Canada's current policy on stem cell research. Write a letter to the editor of a newspaper, explaining your position on the issue. Back up your opinions with as many facts as possible.