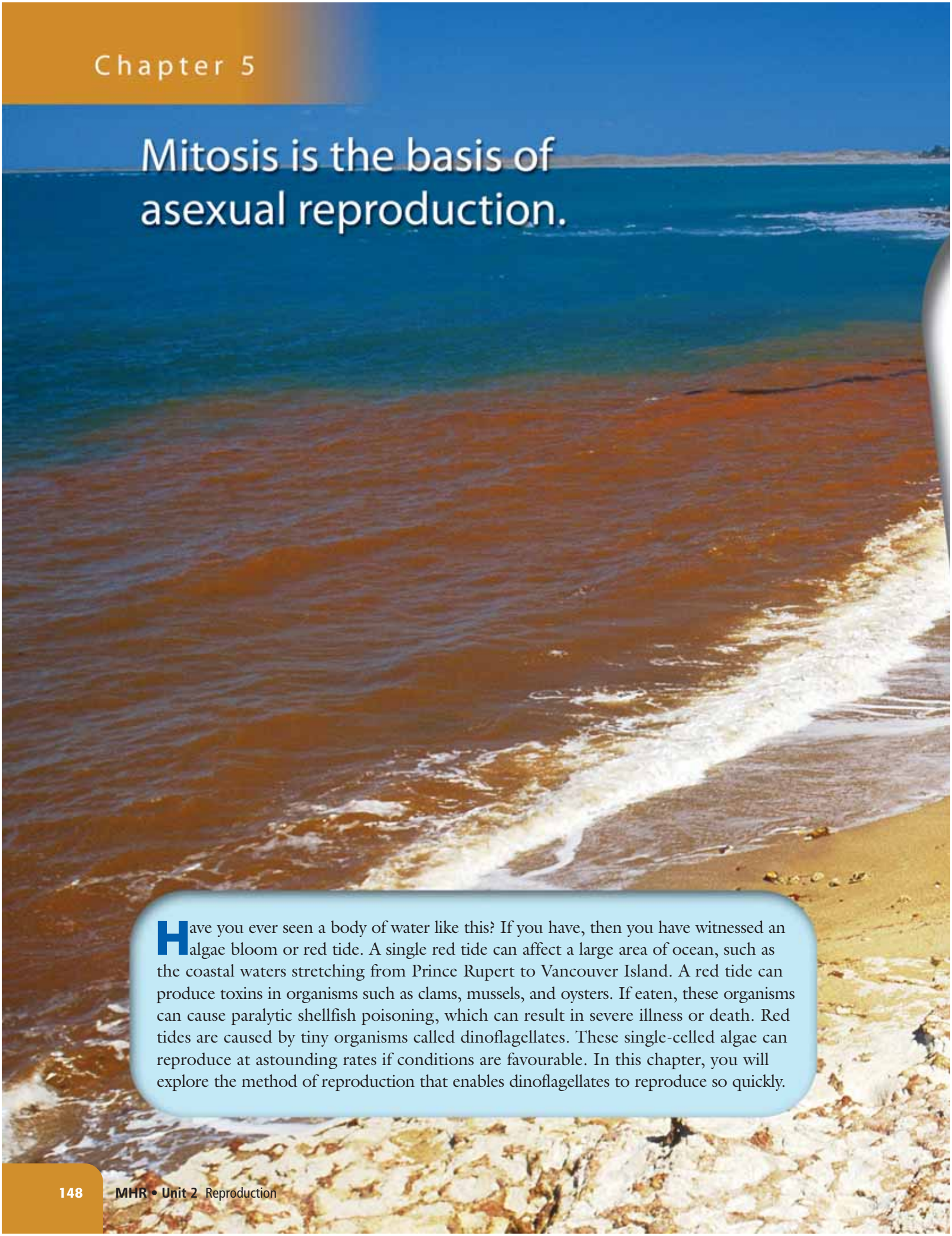
Chapter 5

Mitosis is the basis of asexual reproduction.



Have you ever seen a body of water like this? If you have, then you have witnessed an algae bloom or red tide. A single red tide can affect a large area of ocean, such as the coastal waters stretching from Prince Rupert to Vancouver Island. A red tide can produce toxins in organisms such as clams, mussels, and oysters. If eaten, these organisms can cause paralytic shellfish poisoning, which can result in severe illness or death. Red tides are caused by tiny organisms called dinoflagellates. These single-celled algae can reproduce at astounding rates if conditions are favourable. In this chapter, you will explore the method of reproduction that enables dinoflagellates to reproduce so quickly.

What You Will Learn

In this chapter, you will

- **demonstrate** an understanding of the cell cycle
- **explain** what happens to the chromosomes, nucleus, and cell membrane during mitosis
- **relate** errors that occur in the cell cycle to the development of cancer
- **compare** the advantages and disadvantages of asexual reproduction

Why It Is Important

Understanding mitosis and asexual reproduction is important for understanding how our body cells maintain themselves and how certain organisms in our environment reproduce. Such knowledge has been used for centuries to develop food crops and most recently to clone animals.

Skills You Will Use

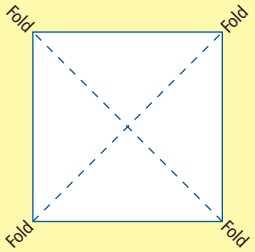
In this chapter, you will

- **model** the cell cycle
- **observe** asexual reproduction
- **graph** results

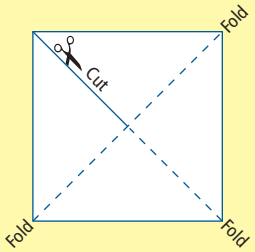
FOLDABLES™
Reading & Study Skills

Make the following Foldable and use it to take notes on what you learn in Chapter 5.

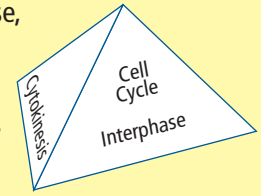
STEP 1 **Fold** a large square of paper diagonally to form an X as illustrated.



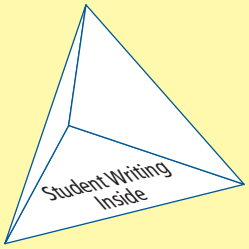
STEP 2 **Cut** along one of the fold lines, stopping at the centre intersection point. This cut will form two "legs" or sections.



STEP 3 **Fold** and glue one of these legs under the other to form a three-sided pyramid. Use a computer to generate four labels—Cell Cycle, Interphase, Mitosis, Cytokinesis—and glue them onto the outer sides of the pyramid.



STEP 4 **Lay** the pyramid on its side to write notes inside on the triangular sections.



Show a Cycle This pyramid is perfect for illustrating cycles that occur in threes or other information that is always in threes. For example, this pyramid could be used for the water cycle (evaporation, condensation, precipitation); the states of matter (solid, liquid, gas); or the three types of galaxies (irregular, spiral, elliptical).

5.1 The Cell Cycle and Mitosis

There are three stages in the cell cycle. Interphase is the stage in which cells carry out the functions necessary for survival and cells that divide prepare for cell division. Mitosis divides the duplicated contents of the cell's nucleus into two equal parts. Cytokinesis separates the two nuclei and cell contents into two daughter cells. Proteins monitor the activities of the cell at checkpoints in the cell cycle. Cancer may result when errors occur in the cell cycle.

Words to Know

cancer
cell cycle
cytokinesis
interphase
mitosis
replication
spindle fibres

If you look around your home carefully, you will find some skin cells left behind by your family or friends. That grey dust ball in the corner is mostly human skin. The tiny flakes of skin that we lose on a daily basis create more than 70 percent of the dust in your home and in your classroom. Each day, you shed millions of skin cells per hour (Figure 5.1). Each month, you completely replace the outer layer, or epidermis, of your skin.

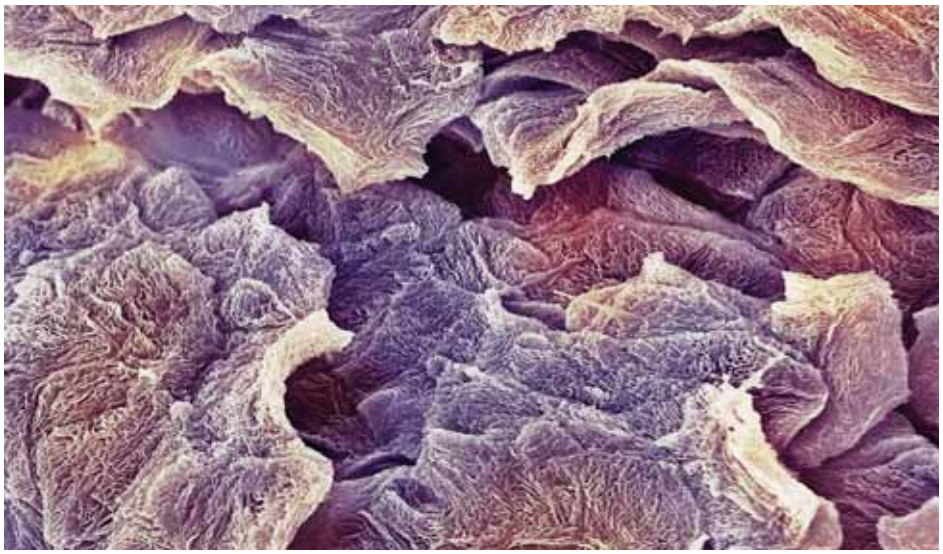


Figure 5.1 Dead skin cells. You are constantly shedding your outer layer of skin cells. Replacement skin cells form underneath this layer.

Word Connect

The word "amphibian" refers to an organism that can live both in water and on land. Amphibian comes from the Greek words *amphi*, which means on both sides, and *bios*, which means life.

When humans shed millions of skin cells each day, it is really not noticeable. Other animals such as snakes and lizards shed their whole skin at once. You may find a shed snake skin in your backyard or when hiking in a park. Replacing worn-out skin cells is an ongoing process for humans. For snakes, shedding occurs several times a year, and each shed takes several days. Newly hatched snakes may shed their skins twice a month, whereas adult snakes shed three to four times a year.

In 2006, scientists reported that a legless, underground-dwelling amphibian, called *Boulengerula taitanus*, develops a new layer of skin for a different reason. *B. taitanus* is found in Kenya, Africa, and hatchlings are

born with specialized teeth for peeling and eating skin. Their mother's skin is thick and rich in fat, and the young strip off and feed on her skin for up to four weeks.

Biologists report that the young press their heads against their mother, move over her body, and repeatedly chew on her skin with their specialized teeth (Figure 5.2A). Some teeth are spoon-shaped for scraping, and some have spiked points for piercing the skin. Other teeth look like grappling hooks with a claw-like structure on one end designed for staying tightly attached to the mother (Figure 5.2B). A mother loses 14 percent of her body weight during this feeding period and does not appear to be harmed.

The process of producing new skin for replacement, for growth, or, in the case of *B. taitanus*, for lunch, requires that cells divide. Cell division is strictly controlled by specialized proteins in the nucleus.

Did You Know?

You have 50 million trillion to 100 million trillion cells in your body. Every minute your body produces about 300 million new cells.

A

B

Figure 5.2 Young *B. taitanus* feeding on mother's skin (A). Close-up of one of the types of teeth used to strip off the mother's skin (B).

5-1A From One Cell to Many Cells

Find Out ACTIVITY

B. taitanus mothers must produce new skin cells to nourish their offspring for up to four weeks. In this activity, you will calculate how many skin cells will result from just 1 cell that continually divides during a 30 d period.

What to Do

1. Copy the cell division chart below into your notebook.

Day	Number of Cells	Day	Number of Cells	Day	Number of Cells
1		11		21	
2		12		22	
3		13		23	
4		14		24	
5		15		25	
6		16		26	
7		17		27	
8		18		28	
9		19		29	
10		20		30	

2. Assume that the cells divide once a day. Calculate how many cells will result in 30 d, if the cells do not stop dividing at any time during the 30 d period.
3. A mass of cells would become just visible to the eye at about 1 mm in width, which is about 250 000 cells. Calculate approximately on which day the cells would be visible.

What Did You Find Out?

1. On which day would the cell mass be visible? Explain.
2. If scientists can detect a tumour when it is about 1 cm in width, how many days would the cells have to divide for the tumour to reach this size?
3. What do you think would happen if all cells in the human body continually divided without stopping?
4. Look at the pattern in the numbers you entered in the chart. How could you quickly calculate the number of cells that would be present after a particular number of days had passed?

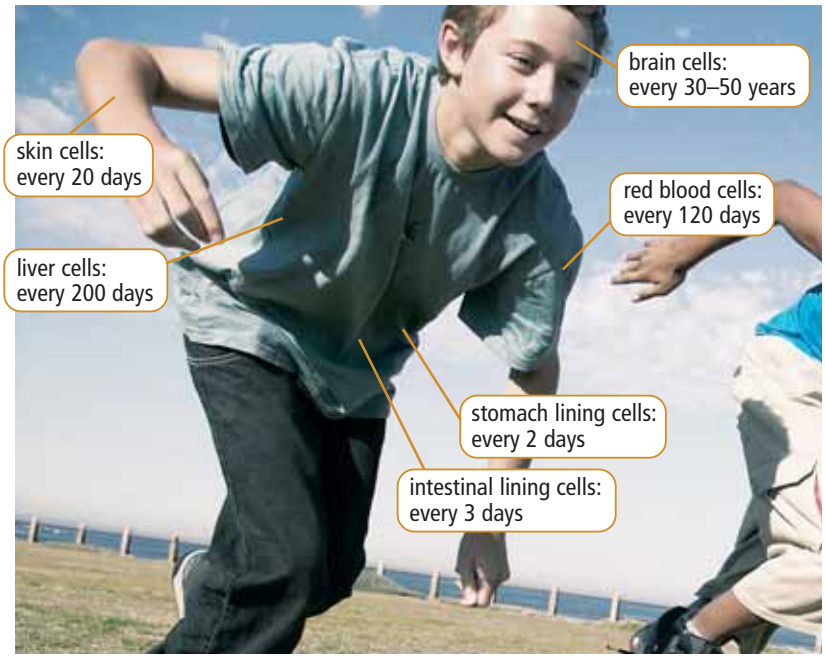


Figure 5.3 Cells in the human body divide at different rates.

Cell Replacement and Development

From the time your life began as a fertilized egg, your cells have continued to divide as you continued to grow. After puberty, your body growth slows. But your body will continue to replace cells that take a lot of wear and tear such as skin cells, stomach cells, and intestinal cells. Cells such as muscle and nerve cells usually do not continue to divide in an adult, but they do continue to carry out functions necessary for survival. Figure 5.3 shows the different life spans of a variety of human body cells.

The Cell Cycle

The life of a cell is divided into three stages known as the **cell cycle** (Figure 5.4). The stages of the cell cycle are interphase, mitosis, and cytokinesis.

- Interphase is the stage in which cells carry out the functions necessary for survival and cells that divide prepare for reproduction.
- Mitosis divides the duplicated contents of the cell's nucleus into two equal parts.
- Cytokinesis separates the two nuclei and cell contents into two daughter cells.

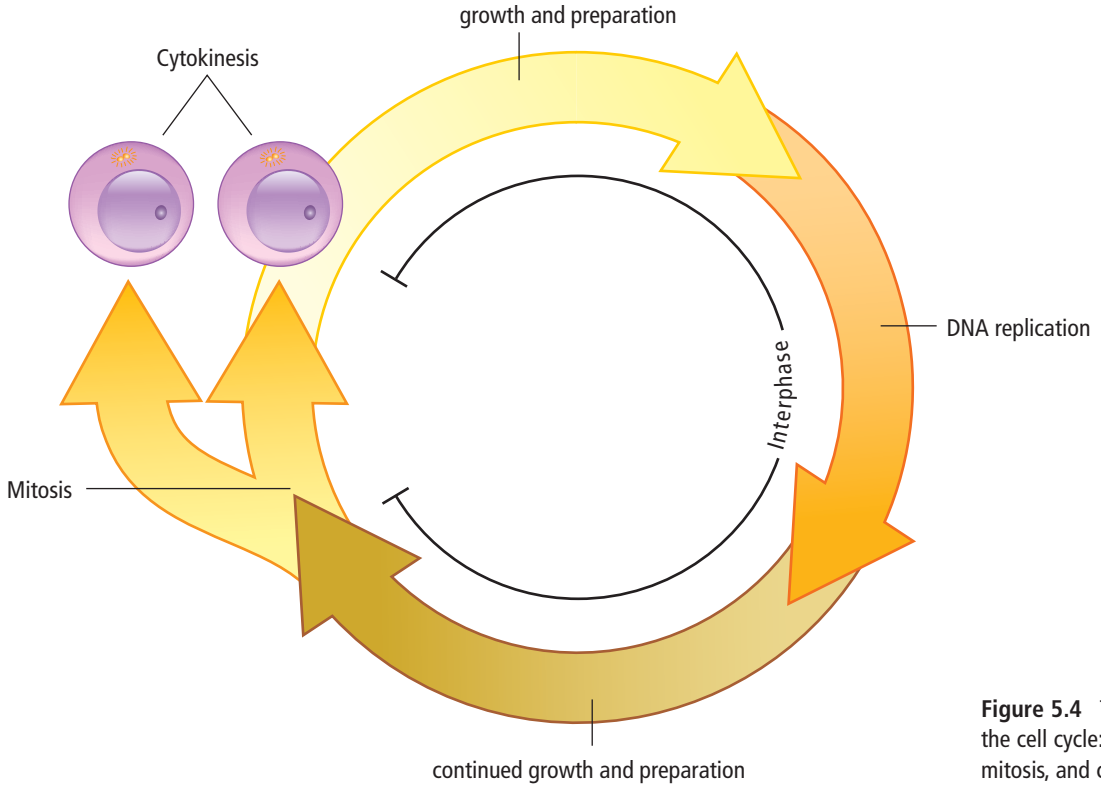


Figure 5.4 The stages of the cell cycle: interphase, mitosis, and cytokinesis

Interphase

Figure 5.4 shows that **interphase** is the longest stage in the cell cycle. This is a time when a cell carries out its various functions within the organism. For example, a cell in your stomach lining might be making and releasing enzyme molecules that aid in digesting the food you eat. During interphase, the cell roughly doubles everything in its cytoplasm.

Growth and preparation

During the first phase of interphase, a cell increases in size and makes the proteins and molecules necessary for the cell to function. Some organelles begin to duplicate.

Replication

In the next phase, DNA copies or makes a "replica" of itself in a process called **replication**. During replication, the cell copies the 3 billion base pairs of DNA information in the nucleus of the cell. Then the cell temporarily has two complete sets of DNA. Enzymes control this process.

To replicate itself, the DNA molecule unwinds and the steps of the DNA ladder break apart as shown in Figure 5.5. Each side then becomes a pattern or a template on which a new side forms. In section 4.1, you saw that base A will pair with base T, and base G will pair with base C. The process of replication results in two new DNA molecules that have the same sequence of bases as the original DNA molecule.

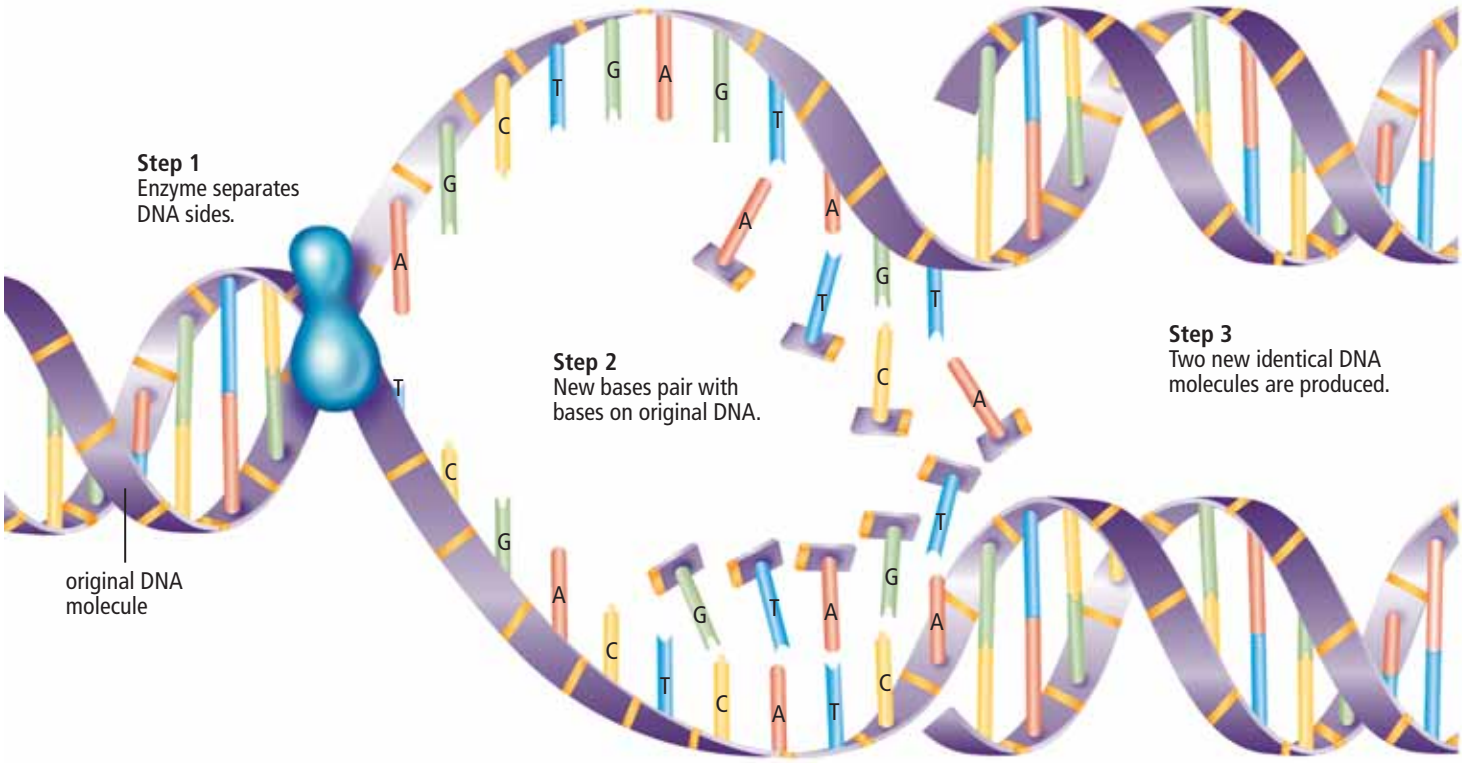


Figure 5.5 During replication, the steps of the DNA ladder break apart with the help of an enzyme.

Replicating DNA ensures that newly formed cells will have an identical copy of the genetic information contained in the original DNA molecule.

Continued growth and preparation

After the DNA replicates, the cell continues to grow and is active making materials such as proteins for the new cells that will be formed after cytokinesis. Early biologists referred to these cells as "daughter cells," and scientists continue to use this term today. The chromatin, which contains the replicated DNA, is in its loosely coiled form (Figure 5.6A and Figure 5.6B). In its loosely coiled form, the DNA can be copied into RNA so that proteins can be made in preparation for cell division. In addition, during this final phase before cell division, organelles such as mitochondria and chloroplasts will be duplicated.

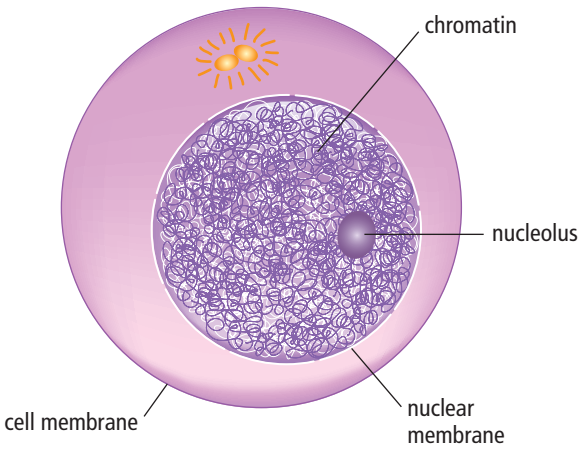


Figure 5.6A Chromatin, which contains the DNA, is located in the nucleus.

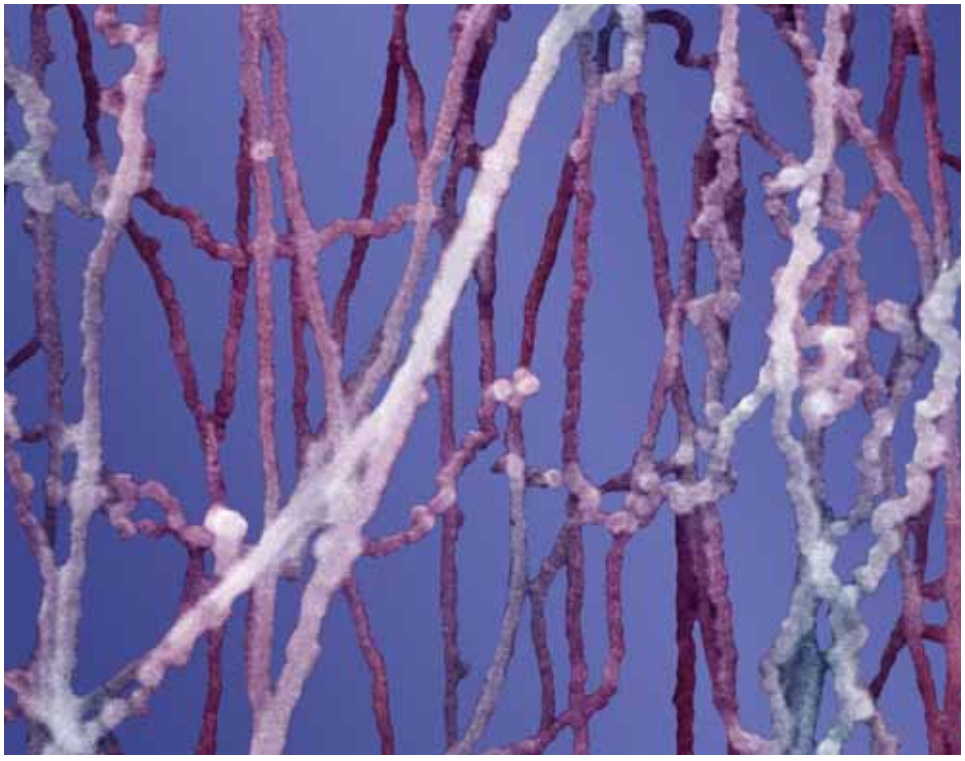


Figure 5.6B DNA is uncoiled during interphase so that proteins required for cell division can be made.

Reading Check

1. Explain why the skin cells of an adult must divide.
2. List the three stages of the cell cycle.
3. What are the events that take place during interphase?
4. Why is DNA replication so important?
5. What does DNA look like at the end of interphase?
6. How does the cell prepare for cell division?

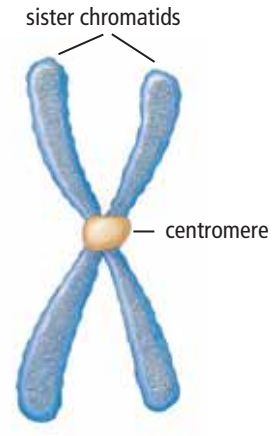


Figure 5.7 The sister chromatids of a replicated chromosome are joined by a centromere.

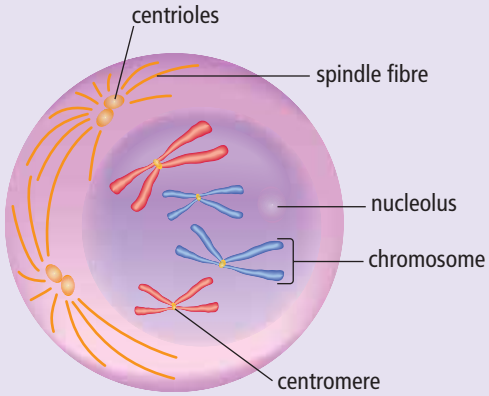
Mitosis

Mitosis is the next stage of the cell cycle and is usually the shortest. Mitosis is the process in which the contents of a cell's nucleus divides. This division results in two daughter nuclei, each with the same number and kinds of chromosomes as the original cell. Occasionally, mistakes are made during replication, but the daughter cells are usually identical to the parent. Therefore, as you learned in section 4.2, most mutations result in little change.

As the nucleus prepares to divide, the DNA molecules that replicated during interphase join together to form the **sister chromatids** of a chromosome. The **centromere** joins the sister chromatids as shown in Figure 5.7.

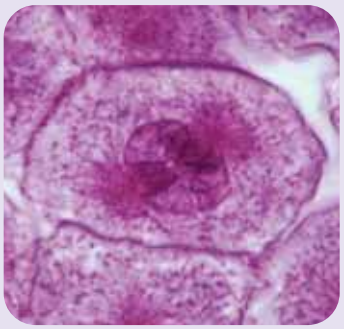
Figure 5.8 shows the phases of mitosis.

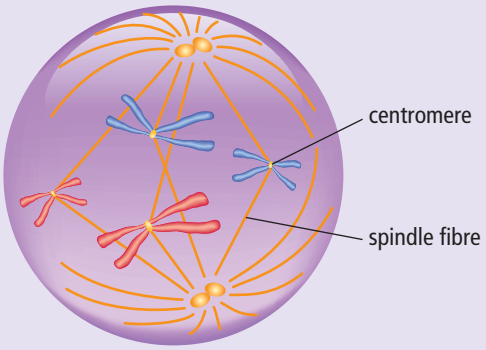
Figure 5.8 Mitosis in a typical animal cell. Notice that, at the end of mitosis, each nucleus has the same number and kind of chromosomes.



Early prophase

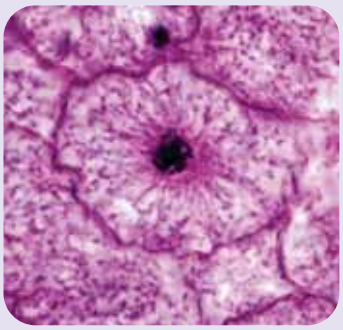
The replicated chromosomes coil up into X-shaped chromosomes and become visible under a light microscope. The nucleolus will disappear, and the nuclear membrane will begin to break down. In animal and plant cells, **spindle fibres**, which are tiny tube-like structures made of protein, begin to form. Spindle fibres stretch across the cell from centrioles that have moved to opposite ends (poles) of the cell. Centrioles are organelles that "organize" spindle fibres during mitosis. In animal cells, the centrioles begin to move apart. (You can observe a similar process in the cells of plants, fungi, and some protists. They also form spindle fibres but not centrioles.)

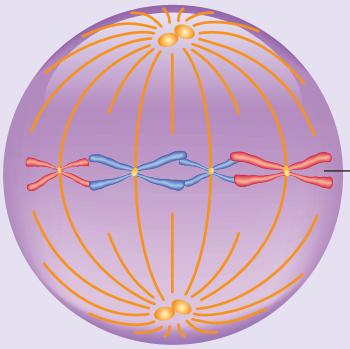




Late prophase

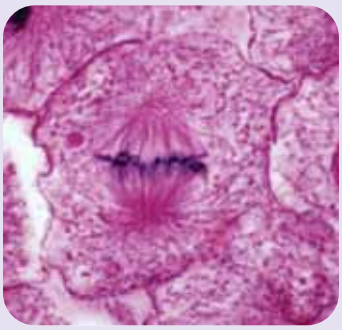
The spindle fibres complete forming. The chromosomes attach to the spindle fibres at their centromeres, and the nuclear membrane disappears.

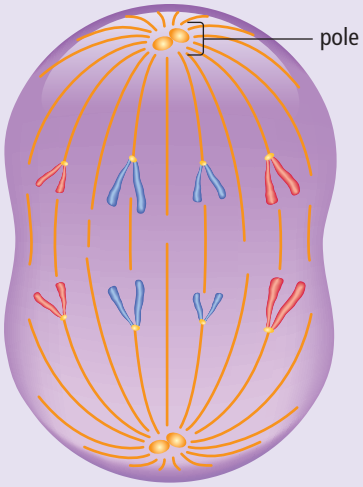




Metaphase

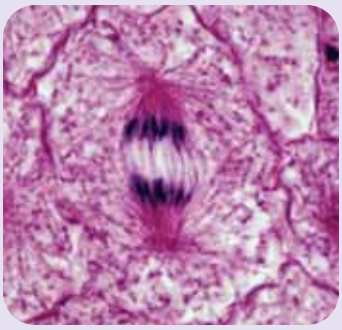
The tugging action of the spindle fibres pulls the X-shaped chromosomes into a single line across the middle (or equator) of the cell.

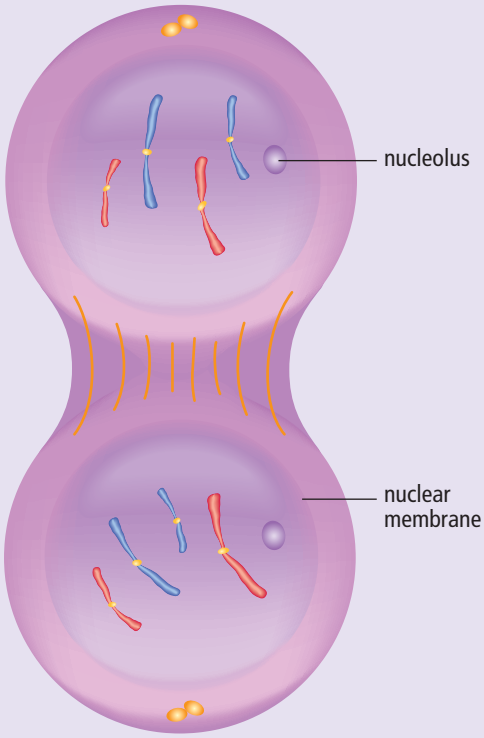




Anaphase

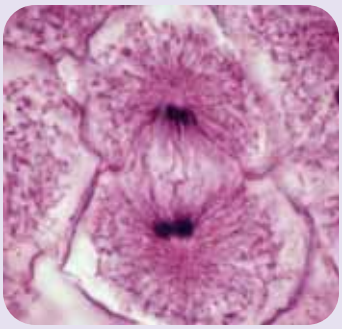
The spindle fibres begin to contract and shorten. This action pulls the centromere apart, allowing the sister chromatids to move to opposite poles of the cell. Once they separate, each sister chromatid is considered to be a chromosome.





Telophase

In the final stage of mitosis, one complete set of chromosomes is now at each pole of the cell. The spindle fibres begin to disappear, and a nuclear membrane forms around each set of chromosomes. A nucleolus appears within each nucleus. Now there are two nuclei in one cell, and the cell is ready to divide.



Word Connect

The word "cytokinesis" has two Greek roots: *cyto*, which means cell, and *kinesis*, which means movement.

Cytokinesis

The final stage of the cell cycle is called **cytokinesis**. Cytokinesis separates the two nuclei into two daughter cells. These new cells are identical to the original parent cell. In animal cells, the cell membrane pinches together to divide the cell's cytoplasm and organelles, as shown in Figure 5.9. In plant cells, a cell plate forms along the centre of the cell to divide the cell into two daughter cells (Figure 5.10).

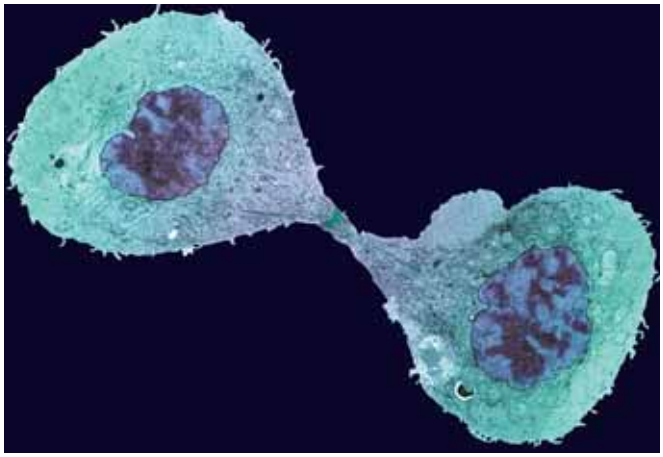


Figure 5.9 Cytokinesis in skin cells. Once mitosis is complete in animal cells, the cell membrane pinches together and the cytoplasm divides.

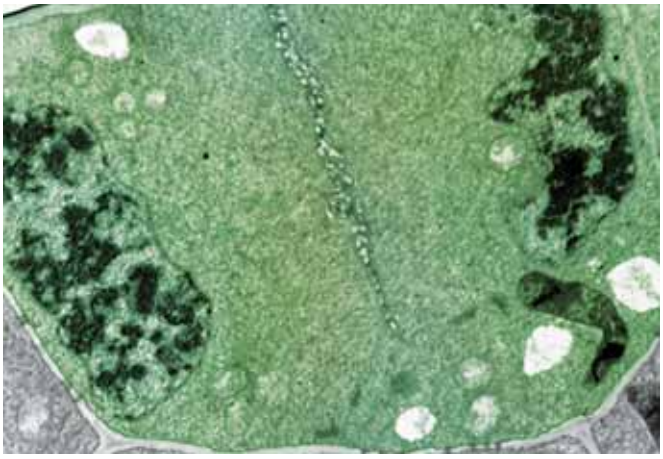


Figure 5.10 Cytokinesis in a coleus plant cell. A cell plate is forming (crossing the middle of the picture) and contains materials to form a new cell wall and membrane.

5-1B The Cell Cycle: A Play in Six Scenes

Find Out ACTIVITY

There are many changes occurring within the cell and cell nucleus during the cell cycle. In this activity, you will increase your understanding of the cell cycle by participating in a play about the cell cycle as an audience member and as an actor.

What to Do

1. Your teacher may assign you to an acting troupe, or you may choose your own group members.
2. Choose **one** of the following events of the cell cycle, which includes the phases of mitosis, for your scene of the play: interphase including DNA replication, prophase, metaphase, anaphase, telophase, or cytokinesis.
3. In your group, review and discuss what the cell would be doing during the event of the cell cycle you have chosen.
4. Prepare a brief script for your cell cycle event. Include a list of props that you will use in your scene.
5. Practise and then perform your scene for the rest of the class.

What Did You Find Out?

1. Is any cell cycle event more active than another event? Explain.
2. To perform a play well, actors must know their lines and where they should stand. How is the process of mitosis similar to what actors must do in a play? What would happen to a cell if chromosomes did not "know" their roles or where they must move during mitosis?
3. What part of developing your group's scene did you enjoy most? Why?
4. After viewing other groups' presentations, reflect on how the scene you performed could be improved.

Checkpoints in the Cell Cycle

Activities within the cell during the cell cycle are monitored and controlled at specific stages, or checkpoints. Checkpoints in the life of a cell are like checkpoints during a mountain bike race. Officials monitor racers to ensure that competitors have enough water and food and that no one is hurt. If an official thinks a racer cannot complete the race because of injury, the racer will be removed from the race.

Checkpoints during the cell cycle have a similar function. Special proteins at these checkpoints monitor cell activities and send this information to the nucleus. The nucleus then instructs the cell whether or not to divide. Cells will not divide if:

- There are not enough nutrients to support cell growth.
- DNA within the nucleus has not been replicated.
- DNA is damaged.

Figure 5.11 shows the specific checkpoints in the cell cycle.

internet connect

To find out more about the cell cycle, go to **www.bcscience9.ca**.

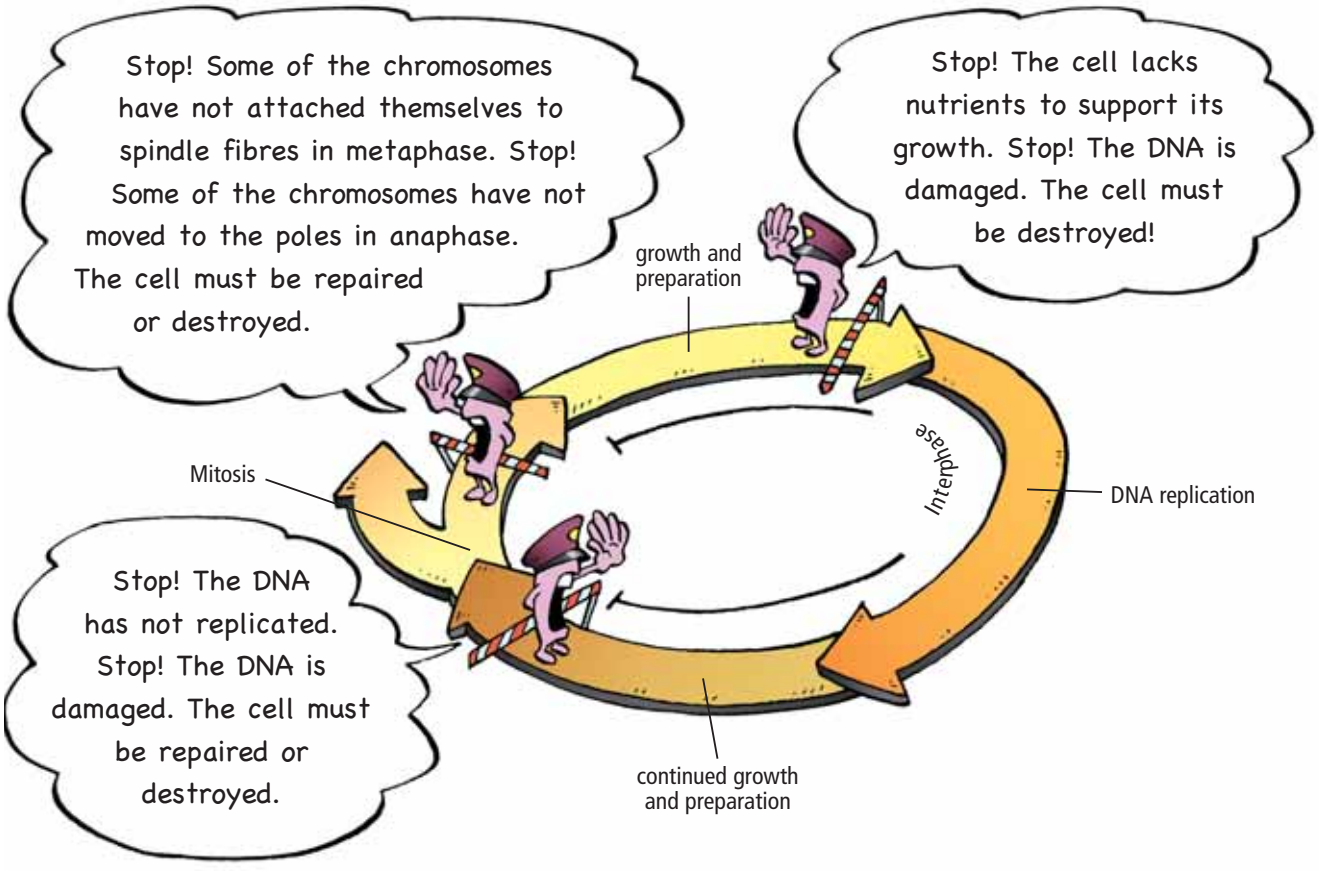


Figure 5.11 Checkpoints in the cell cycle

The Cell Cycle and Cancer

You have seen that checkpoints in the cell cycle can stop the cell from growing or dividing. Such precise control of the cell cycle is important to the survival of an organism. In section 4.2, you learned that mutagens can cause mutations in a cell and may harm the organism. These mutagens can include viruses, X rays, ultraviolet light, and chemicals such as acetone in cigarettes. Figure 5.12 shows the effect of radiation on a cell during mitosis. Skin cancer may eventually result from a single lengthy exposure to the Sun (Figure 5.13).

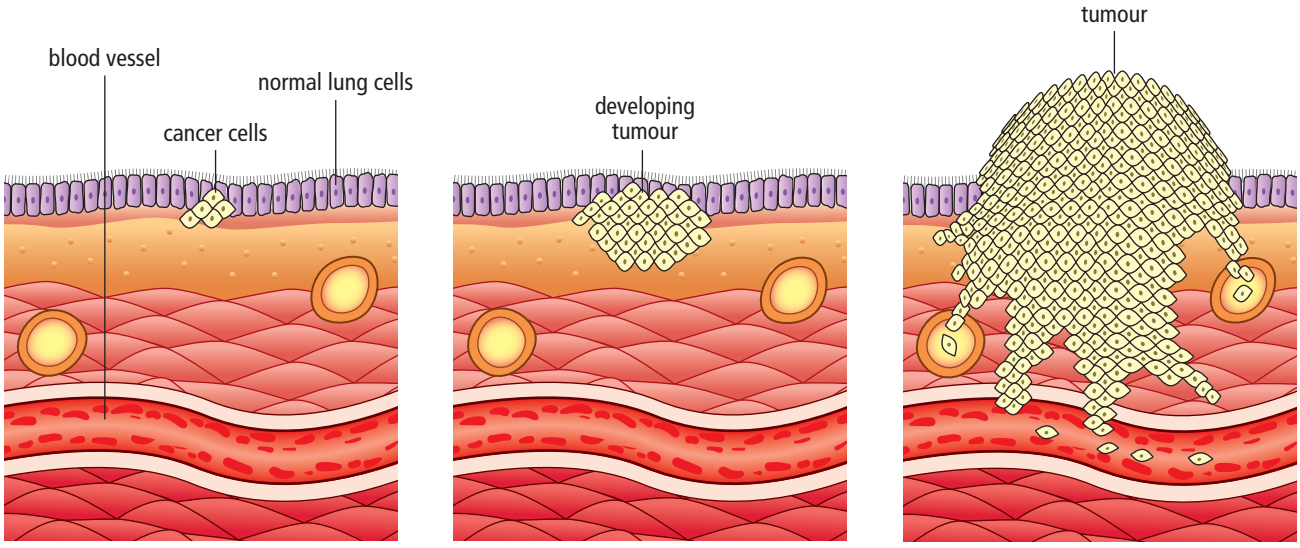
Figure 5.12 The effect of radiation on cells in mitosis. Here some chromosomes fail to move to opposite poles of a cell during anaphase.

Figure 5.13 A severe sunburn is a risk factor for developing skin cancer.

If a mutation occurs in a gene producing the instructions for a checkpoint protein, cell cycle control will be lost. As a result, a damaged cell like the one in Figure 5.12 may divide uncontrollably. **Cancer** is the name given to certain diseases that result from uncontrolled cell division. Researchers have linked certain types of inherited colon cancer and breast cancer with gene mutations in checkpoint proteins.

Healthy, normal cells grow in a single layer and stop dividing when they receive messages from neighbouring cells. Cancer cells, however, do not respond to messages from nearby cells, so they begin to grow in multiple layers. These multiple layers form a tumour as shown in Figure 5.14 on the next page.

When viewed with a microscope, cancer cells also show large, abnormal nuclei. These large nuclei result because cell division checkpoints no longer function and the chromosomes do not divide correctly.



A few abnormal-looking (cancer) cells are growing.

Cancer cells multiply to form a tumour.

Some cancer cells break away, move into the bloodstream, and spread to a new location.

Figure 5.14 A cancer cell divides uncontrollably and becomes a tumour. Nearby blood vessels provide nutrients to the tumour and carry cancer cells to new locations.

Cancer cells are not specialized, so they do not function as part of your body. A cancer cell formed in your lungs does not function as a lung cell because the cancer cell does not make the proteins for a lung cell. However, cancer cells can release chemicals to attract small nearby blood vessels. The blood vessels branch into the tumour and deliver nutrients to it. Nutrients feed the growing tumour, and tumour cells divide even more rapidly. Cancer can spread to other areas of the body if some tumour cells break away and are carried by the blood vessels to a new location where they may begin to divide and form a new tumour.

Cancer researchers strive to understand how cancer can disrupt the cell cycle, especially by looking for mutated genes that produce non-functioning checkpoint proteins. Cancer researchers also work to identify potential treatments, such as drugs that work by blocking cell division in a cancer cell and preventing the formation of a tumour.

Explore More

Scientists have found that for a cell to become cancerous it must have several mutations in its checkpoint proteins. This explains why the risk of cancer increases as you grow older. Find out more about the relationship between age and cancer. Begin your search at **www.bcscience9.ca**.

Reading Check

1. What are the phases of mitosis?
2. What do the nucleus and chromosomes look like during prophase?
3. How does cytokinesis differ in plant and animal cells?
4. What is the importance of checkpoints in the cell cycle?
5. What may happen when checkpoint proteins no longer function?

5-1C Observing the Cell Cycle in Plant Cells

SkillCheck

- Observing
- Modelling
- Working co-operatively
- Graphing

Science Skills

Go to Science Skill 9 for information about using a microscope and Science Skill 6 for information on making scale drawings.

Safety

- Microscopes, slides, and cover slips can break, especially when using the high-power objective lens. Handle with care.

Materials

- ruler
- pencil
- microscope
- prepared slide of an onion root tip

The cells in the tips of onion roots constantly divide as the tip grows. In this activity, you will work in groups to observe the cells of onion root tips to determine the frequency of the events of the cell cycle.

Question

What is the frequency of the events of the cell cycle in an onion root tip?

Procedure

1. In your notebook, draw six boxes that are 30 mm high by 20 mm wide. Use a ruler to draw the boxes.
2. Label the boxes: prophase, metaphase, anaphase, telophase, cytokinesis, and interphase.
3. Place the onion root tip slide on the stage of the microscope, and focus on the tip of the root at low power.
4. Change the objective lens to medium power, refocus, and then move to high power. Review the diagrams and micrographs on pages 156 to 158. Find a cell in prophase and draw it in the prophase box. Let the lines of the box represent the walls of the cell. Label the chromosomes and the spindle fibres.
5. Find a cell in metaphase, anaphase, telophase, and cytokinesis and draw your observations in the appropriate boxes.
6. After you have observed and drawn each of the above events, copy the chart below into your notebook. In your group, you will determine the number of cells in each event of the cell cycle. This is called the frequency. Follow steps 7 to 11 to complete the chart.

Cell Cycle Event	Group Data		Class Data	
	Frequency (number of cells)	Percentage	Frequency (number of cells)	Percentage
Prophase				
Metaphase				
Anaphase				
Telophase				
Cytokinesis				
Interphase				
Totals				

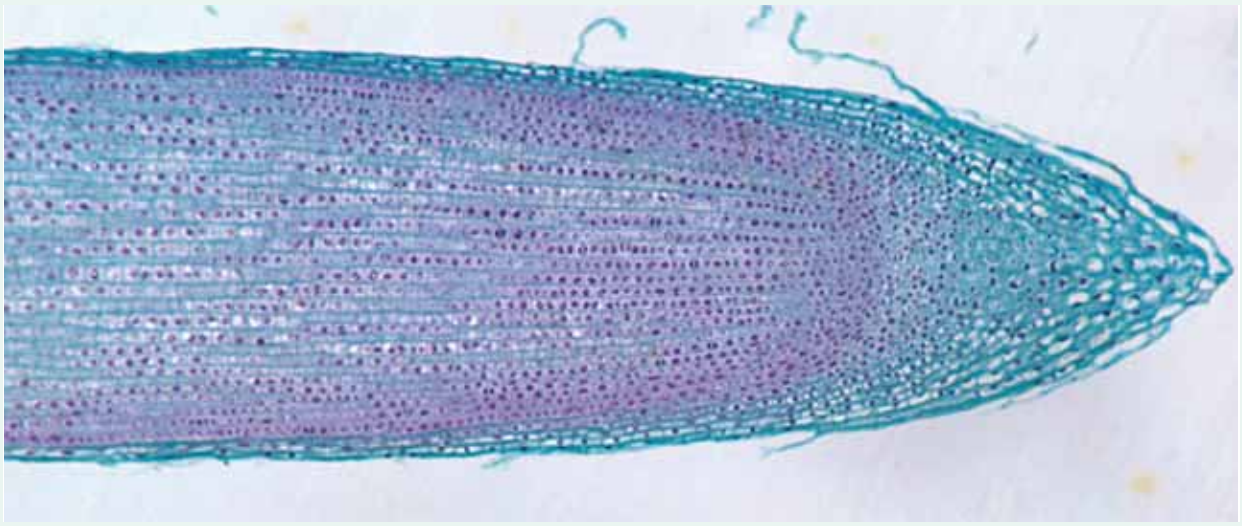
7. Count the number of cells across your field of view. Then count the number of rows of cells in the field. Multiply these two numbers together. This will give you an estimate of the total number of cells in your field of view. Record this estimate in the last box of the first column of the chart.
8. Have the person viewing the cells under high power call out the number of cells he or she can see in prophase. Have another person record this number in the prophase box in the table.
9. Repeat step 8 for each of the other events except interphase. Try not to count the same cell showing the same event twice. (You will determine the number of cells in interphase in step 10.)
10. Add together the number of cells seen in each event. Subtract this total from the number you estimated in step 7. This will give you the number of cells in interphase. Record this number in the chart.
11. Calculate the percentage for each event.
12. Share your results with the rest of the class and calculate total class frequencies.
13. Calculate class percentages for each event.
14. Plot a bar graph using the class data percentages.
15. Clean up and put away the equipment you have used.

Analyze

1. Which event of the cell cycle occurs most frequently?
2. How can you tell that the cell cycle is a continuous process?
3. (a) Which event of the cell cycle takes the longest period of time?
   (b) Explain how you made your decision.
4. Are your individual results in this investigation different from the rest of the class? If so, how could you explain this?

Conclude and Apply

1. Suppose that you were told that the cell cycle lasts 16 h. Use your class data percentages to estimate the length of each of the six events in this 16 h cycle.
2. Many scientific and medical careers involve examining cells in great detail. Find out about and summarize what a technician in a medical laboratory does. Begin your research at **www.bcscience9.ca.**



The growing tip of an onion root

Science Watch

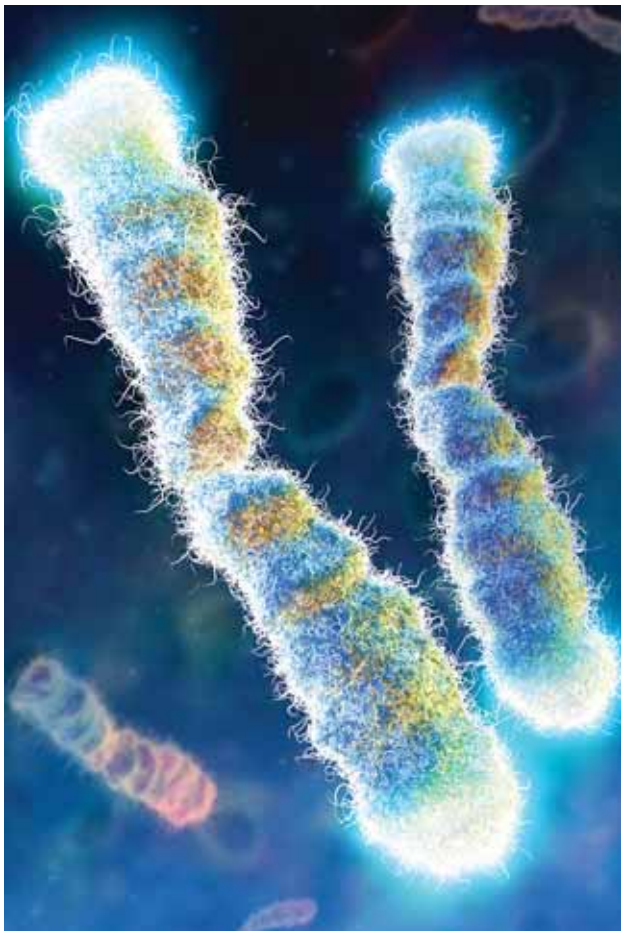
Stopping the Cell Cycle Clock

A cell cannot live forever, and eventually its cell cycle stops. On average, a human cell can divide only about 50 times. Embryonic stem cells are different. They are the early stage cells of a developing embryo. (An embryo is the early stage of development of a multicellular organism.) Scientists have discovered that embryonic stem cells have the potential to live indefinitely. However, once a cell becomes specialized, this fountain of youth is lost. One of the secret elixirs of stem cells is the enzyme telomerase [teh-loh-MEH-raze], which is found in egg, sperm, and embryonic cells.

Think of your chromosomes as pairs of shoelaces. As shoelaces become worn, the plastic end caps break and the shoelaces begin to fray. At the tips of your chromosomes are telomeres. These telomeres act like plastic shoelace caps to stop chromosomes from fraying and becoming tangled with other chromosomes. Each time your cells divide, your chromosomes shorten by about 50 base pairs. Eventually, the telomere cap disappears and the chromosomes are unable to divide correctly. When this happens, the cell dies.

Telomerase maintains the telomere caps so that the chromosomes do not become frayed. Since almost all cells in your body no longer make telomerase, each of your cells will age and eventually die.

Have researchers found the fountain of youth? Probably not, since there are other factors involved in cell aging. However, scientists have recently found that 90 percent of human cancer cells do not turn off the telomerase gene. Therefore, the telomere caps of these chromosomes do not shorten when the cells divide. As a result, these cells divide for longer than regular cells. Researchers believe that, if they can block the action of telomerase in cancer cells, they will be able to treat the disease and stop the clock of the cancer cell cycle.



Telomeres glow at the end of these chromosomes.

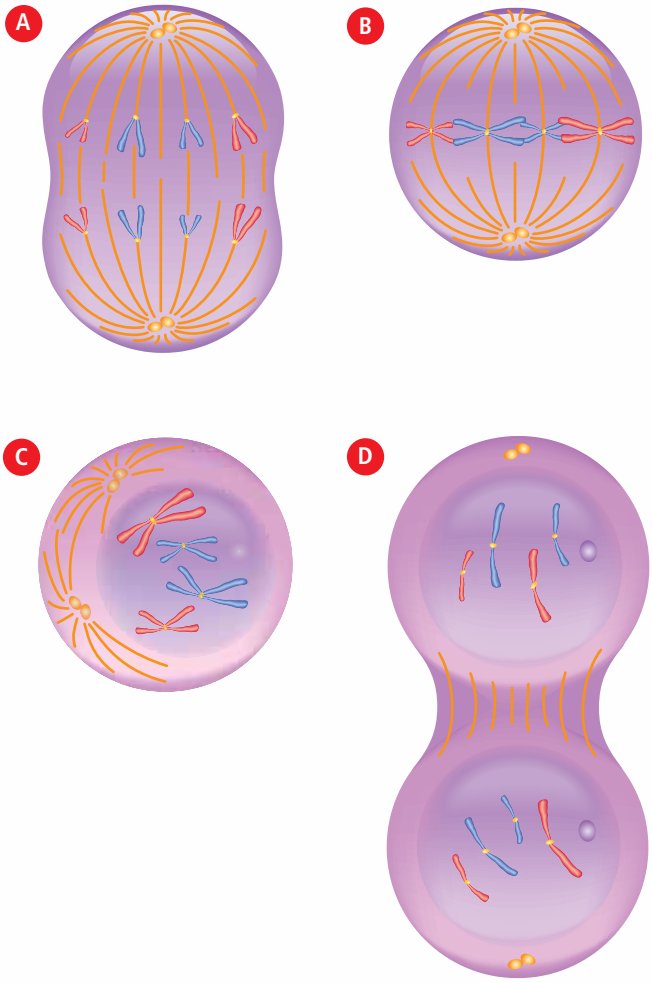
Questions

1. What causes cells to stop dividing?
2. Why is telomerase important to a rapidly dividing cell such as an embryonic cell?
3. How do cancer cells escape programmed cell death?

Check Your Understanding

Checking Concepts

1. Outline the activities in the cell at each of the following phases of interphase:
   (a) growth and preparation
   (b) replication
   (c) continued growth and preparation
2. List the steps in DNA replication.
3. What is the function of mitosis?
4. Is mitosis constantly occurring in your cells? Explain.
5. What is the function of the spindle fibres?
6. Use the diagrams on the right to answer questions (a) to (e).
   (a) Which diagram shows a cell at the beginning of anaphase?
   (b) Which diagram shows a cell with sister chromatids moving to opposite poles?
   (c) Which diagram illustrates a cell where a new nuclear membrane is forming?
   (d) Write down the correct sequence of letters to show the phases of mitosis from beginning to end.
   (e) Using the diagrams, explain how you could tell whether a cell has just completed mitosis or is entering mitosis.



Understanding Key Ideas

7. How is plant cell division different from animal cell division?
8. Why must the nuclear membrane break down for mitosis to occur?
9. In interphase, the DNA is loosely coiled. Why do you think it is important that the DNA be compact and tightly coiled during mitosis? (**Hint:** Think of an unravelled spool of thread.)
10. What might happen if DNA replication and mitosis were not highly controlled?
11. What are some environmental factors that can contribute to the development of cancer?
12. How is a cancer cell different from a normal cell?

Pause and Reflect

Interphase was previously called the resting stage of the cell cycle. Explain why "resting stage" is not an appropriate description.