CHAPTER 8

Cell Growth and Division



As a cell undergoes cell division the two daughter cells pull apart. Before the cell divides, the nucleus must go through a series of stages that ensure that the daughter cells are exact copies of the parent cell (inset).

One of the major characteristics of a living thing is the ability to grow. Growth is obvious when it involves an increase in size. We all notice the growth of grass and flowers in the spring and summer or the growth of a newborn animal into an adult. The growth of an organism results from an increase in the number and the size of the cells within it. But growth occurs even in organisms that are no longer increasing in size—continued cell growth is essential for life.

How do cells grow? Is there a limit to the growth of a cell? In this chapter we will examine how cells grow in size and increase in number, and why growth is so essential to living things.

CHAPTER OUTLINE

8–1 Cell Growth
- Limits of Cell Growth
- Rates of Cell Growth
- Controls on Cell Growth
- Uncontrolled Cell Growth

8–2 Cell Division: Mitosis and Cytokinesis
- Chromosomes
- The Cell Cycle
- Interphase
- Prophase
- Metaphase
- Anaphase
- Telophase
- Cytokinesis

8–1 Cell Growth

Section Objectives

- Describe cell growth.
- Define cell division.
- Relate cell growth to cell division.

As you already know, living things are made up of cells. And living things grow, or increase in size. Does a living thing grow because its cells get larger and larger or does it grow because it produces more and more cells? **In most cases, a living thing grows because it produces more and more cells.** The cells of a human adult are no larger than the cells of a human baby, but there are certainly more of them.

Does growth have to occur in this way? Or could an organism grow simply by allowing its cells to get larger and larger? Let's consider what would happen if this could occur.

Limits of Cell Growth

You will recall from Chapter 5 that it is through the cell membrane that food, oxygen, and water enter the cell and waste products leave the cell. How quickly this exchange takes place depends on the surface area of the cell, or the total area of the cell membrane. How quickly food and oxygen are used up and waste products are produced depends on the cell volume, or the amount of space within the cell.

If we were to take a typical cell and double its diameter, what would happen to the amount of membrane (surface area) compared to the amount of material inside the cell (cell volume)? Look at Figure 8–2 on page 160. Notice that as the cell

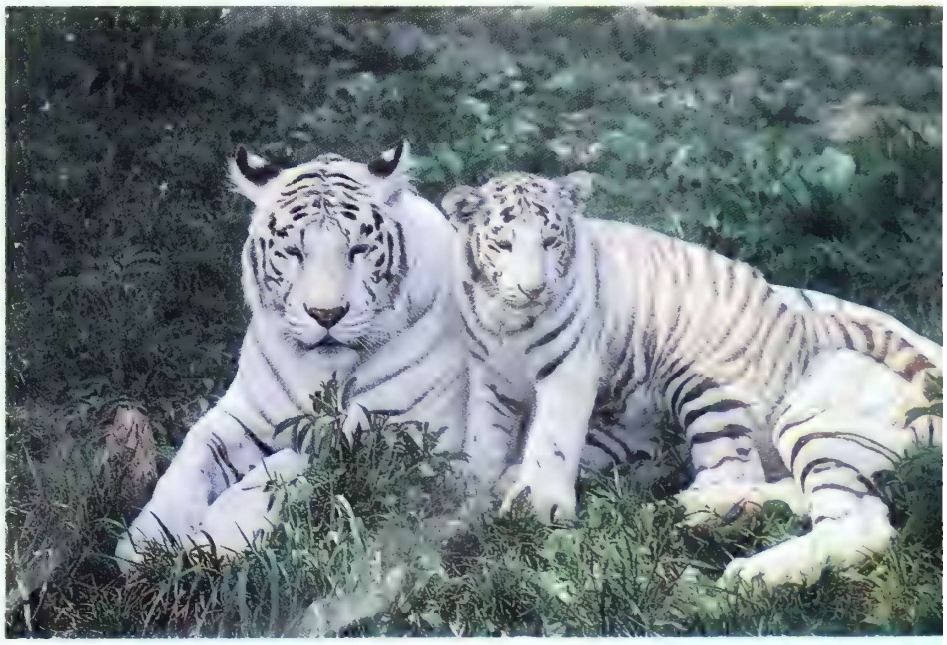
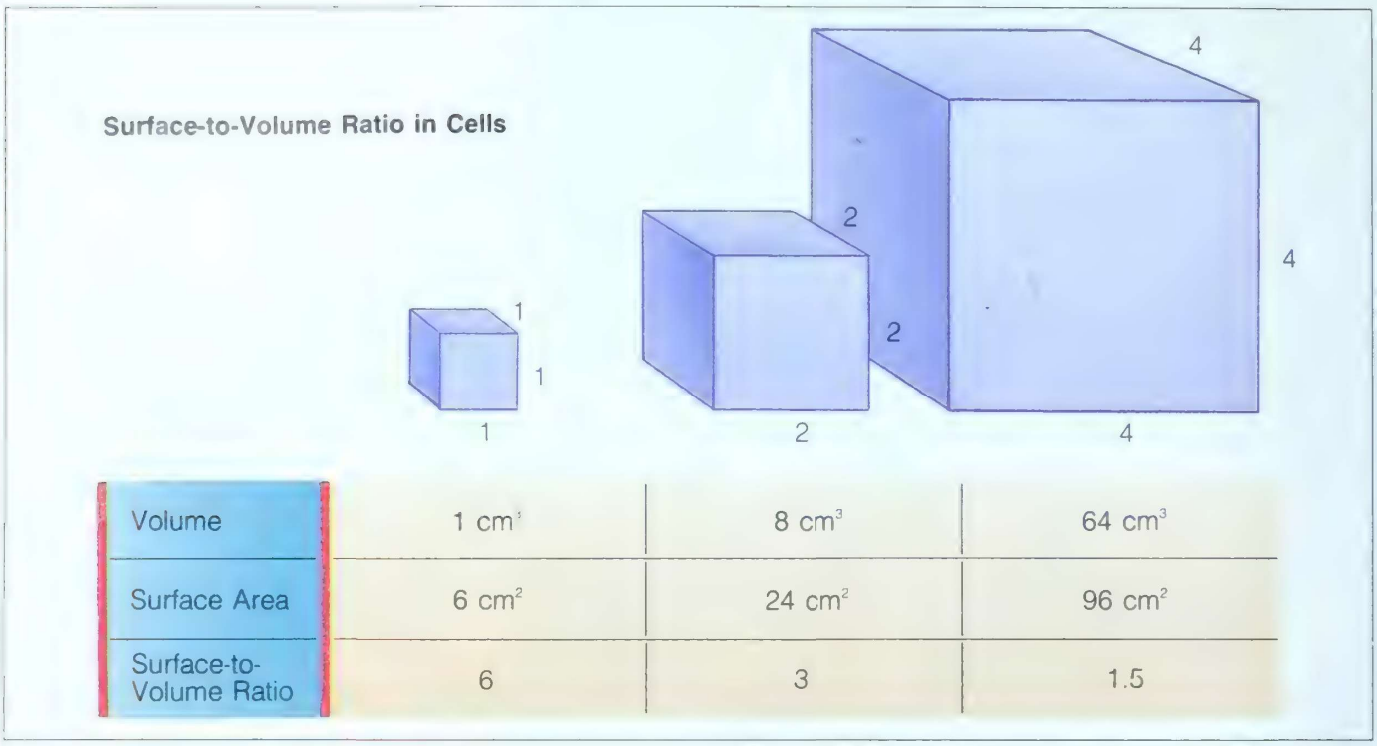


Figure 8–1 *As living things grow they produce more cells. Although this adult white bengal tiger is larger than its cub, the sizes of its cells are the same as those of the cub's.*



Volume	1 cm^3	8 cm^3	64 cm^3
Surface Area	6 cm^2	24 cm^2	96 cm^2
Surface-to-Volume Ratio	6	3	1.5

Figure 8–2 *If the length of each side of a cube-shaped cell doubles from 1 to 2 to 4, the volume increases more rapidly than does the surface area. As a result, the ratio of surface area to volume decreases and the cell with the largest volume has a more difficult time getting materials in and waste products out.*

increases in size, its volume increases at a faster rate than its surface area. For example, if the diameter of the cell increases 10 times, its surface area increases 100 times. Its volume, however, increases 1000 times!

The fact that surface area and volume do not increase at the same rate creates problems for the cell. The larger cell will have a more difficult time getting oxygen and nutrients in and waste products out.

To help you understand why the larger cell has a more difficult time than the smaller cell, let's compare the cells to a small and a large office building. Suppose the small office building that is serviced by a two-lane highway is replaced by a large office building. Now more people work in the office building. But the highway leading to the large building has not increased in size. It is the same two-lane highway that serviced the small office building. As a result, the people in the large building will have difficulty with traffic getting to the office in the morning and leaving the office in the evening.

A larger cell will experience similar problems—materials will have trouble entering and leaving the cell. This is one reason why cells do not grow much larger even if the organism of which they are a part does. There is another reason too.

As you will recall from Chapter 7, information for the cell's function and survival is stored in the sequence of nitrogenous bases in DNA. In eukaryotic cells, the DNA is stored in the nucleus of the cell. When the cell is small, copies of DNA that are stored in the nucleus are able to produce enough messenger RNA to make all the proteins the cell needs. But even though the cell increases in size, it does not make extra copies of DNA.

(There are a few exceptions that we will learn about later.) If a cell were to grow without limit, an "information crisis" would occur. Like a town that has tripled in size but has not added a single book to its library, the cell must now make greater demands on its available genetic library.

In many cases, the amount of messenger RNA that is produced in the cell increases—but within limits. After a time, the cell's DNA may no longer be able to make enough RNA to supply the increasing needs of the growing cell. The cell must slow down its growth, thus becoming less efficient. The cell undergoes a process called **cell division** to solve these problems. **Cell division is the process whereby the cell divides into two daughter cells.** We will discuss cell division in more detail later in the chapter.

Rates of Cell Growth

Cells can grow at astonishing rates. For example, the bacterium *Escherichia coli* (ehsh-uh-RIHK-ee-uh KOH-ligh), or *E. coli*, is a single-celled organism that can easily double its volume in about 30 minutes. It can then divide to form two new cells. If conditions are ideal, each of these cells can grow to form two new cells in the next 30 minutes.

Ideal conditions for this kind of growth can never be maintained for very long, however. A quick look at the consequences of rapid growth will explain why. In just one day, a single cell would grow into a 14-kilogram mass of bacteria. In three days, the mass of the cells would equal the mass of the Earth! Real conditions, or the circumstances that cells normally face, are very different.

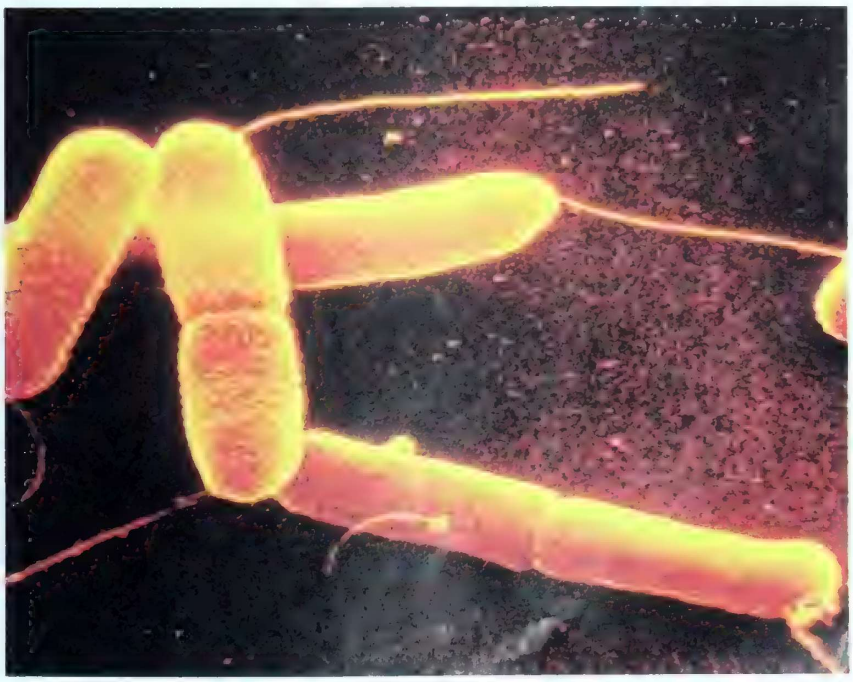


Figure 8–3 *Single-celled prokaryotic organisms reproduce by cell division. In this scanning electron micrograph of bacteria (*E. coli*), you can see two bacteria undergoing cell division.*



Figure 8–4 *The scientist in this photograph is growing pine tree cells on culture plates. As the cells divide they will form a continuous layer, one cell thick, across the surface of each culture plate. But when the cells come in contact with adjacent cells, they will stop growing and dividing.*

Controls on Cell Growth

One of the most striking aspects of cell behavior in a multicellular organism is how carefully cell growth and cell division are controlled. Cells in certain places in the body, such as the heart and the nervous system, rarely divide—if they divide at all. In contrast, the cells of the skin and digestive tract grow and divide rapidly throughout life, providing new cells to replace those that are worn out or broken down due to daily wear and tear.

We can observe the effects of controlled cell growth in the laboratory by placing some cells in a petri dish containing nutrient broth. The nutrient broth provides food for the cells. Most cells will grow until they form a thin layer covering the bottom of the dish. Then the cells will stop growing. Why do they stop growing? When cells come into contact with other cells, they respond by not growing. At present, scientists are trying to understand how this process works.

Controls on cell growth and cell division can be turned on and off. When an injury—such as a cut in the skin or a break in a bone—occurs, cells at the edges of the injury are stimulated to divide rapidly. This action produces new cells, starting the process of healing. When the healing process nears completion, the rate of cell division slows down, controls on growth seem to be reimposed, and everything returns to normal.

Uncontrolled Cell Growth

The consequences of uncontrolled cell growth in a multicellular organism are severe. Cancer, a disorder in which some



Figure 8–5 *Unlike normal cells, cancer cells do not stop growing and dividing even if they come in contact with other cells. Actually, cancer cells, such as those shown in this scanning electron micrograph, have lost their ability to control their own rate of growth.*

PROBLEM SOLVING IN BIOLOGY

SCIENTIFIC NOTATION

How many cells would you suspect there are in the human body? There are approximately 100,000,000,000,000 cells. And all these cells arise from a human egg cell that is only 0.0001 meter in diameter!

As you can see, there are numbers associated with biology that are so large that they are also difficult to write and understand. For this reason, scientific notation is used. Scientific notation is also known as exponential notation because it uses the exponential form of a number.

The exponential form of a number is made up of two parts: $M \times 10^n$
The first part, *M*, is a number between 1 and 10. The second part, *n*, is an exponent, or power, to which the base 10 is raised. An exponent indicates how many times the base is to be multiplied by itself.

Because the base is 10, what the exponent actually does is locate the decimal point in the number being represented. It does this by indicating how many places the decimal point in *M* must be moved. The decimal point is moved to the right if the exponent is positive and to the left if the exponent is negative. A negative exponent is a negative power of 10. It is shorthand for 1 divided by a power of 10.

To convert a large number to scientific notation, follow these steps.

1. Determine *M* by moving the decimal point in the number (100,000,000,000,000) to the left or the right so that only one digit is to the left of it.

1 0 0, 0 0 0, 0 0 0, 0 0 0, 0 0 0.
1.0 0, 0 0 0, 0 0 0, 0 0 0, 0 0 0

2. Determine *n* by counting the number of places the decimal point has been moved. If moved to the left, *n* is positive; if moved to the right, *n* is negative.

1.0 0, 0 0 0, 0 0 0, 0 0 0, 0 0 0 **14 places to the left**

3. Then write the number 1 multiplied by the base 10 with its exponent.

$$1 \times 10^{14} = 100{,}000{,}000{,}000{,}000$$

To convert a small number to scientific notation, follow these steps.

1. Determine *M* by moving the decimal point in the number (0.0001) to the left or the right so that only one digit is to the left of it.

0.0 0 0 1
0 0 0 0 1.

2. Determine *n* by counting the number of places the decimal point has been moved. If moved to the left, *n* is positive; if moved to the right, *n* is negative.

0.0 0 0 1, **4 places to the right**

3. Then write the number 1 multiplied by the base 10 with its exponent.

$$1 \times 10^{-4} = 0.0001$$

Complete the following exercises. Check your answers by using a calculator or computer, if one is available.

A. Expressing Numbers in Scientific Notation

1. The average length of a mitochondrion is 0.00000001 cm.
2. A rat contains approximately 10,000,000,000 cells.

B. Converting Scientific Notation into Numbers

1. The average diameter of a bacterium is 2×10^{-6} cm.
2. The resolving power of an electron microscope is 1×10^{5} times greater than that of the human eye.

cells have lost the ability to control their own rate of growth, is one such example. When cancer cells are placed in a culture of living tissue, they do not stop growing even though they come into contact with other cells. Cancer cells will continue to grow and divide until the supply of nutrients is exhausted.

Cancer is a serious disorder that claims many lives and affects all of us, directly or indirectly. To cell biologists, cancer provides valuable information concerning the importance of controls on cellular growth.

8–1 SECTION REVIEW

1. What is growth? What controls cell growth?
2. What is cell division?
3. A newly discovered strain of bacteria divides once every 60 minutes under ideal conditions. After 24 hours, a single bacterium produces cells that have a mass of 1 kilogram. From this information, calculate the average mass of a single bacterium.

Section Objectives

- Define mitosis and cytokinesis.
- Describe the cell cycle and the changes that take place during interphase.
- Discuss the events and the significance of mitosis.

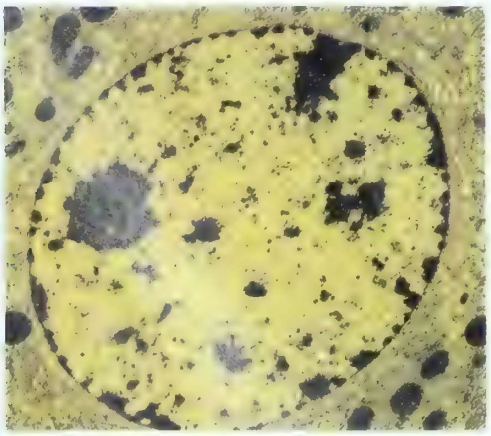
8–2 Cell Division: Mitosis and Cytokinesis

In this section we will discuss how eukaryotic cells divide and form two cells. The division of eukaryotic cells occurs in two main stages. The first stage of cell division is called **mitosis** (migh-TOH-sihs). **Mitosis is the process by which the nucleus of the cell is divided into two nuclei, each with the same number and kinds of chromosomes as the parent cell.**

The second stage of cell division is known as **cytokinesis** (sight-oh-kih-NEE-sihs). **Cytokinesis is the process by which the cytoplasm divides, thus forming two distinct cells.**

Because the structure of a eukaryotic cell is complex, the process of cell division in this type of cell is complex too. The reason for this complexity may be found in the need to separate large amounts of DNA accurately and efficiently. With as many as 100 chromosomes to take care of, a mechanism must exist in the eukaryotic cell to make certain that each new cell gets one (and only one) copy of each chromosome. A mistake in the process could make it impossible for one or both daughter cells to remain alive.

Figure 8–6 When a cell is not dividing, the chromatin forms condensed and dispersed regions.



Chromosomes

You will recall from Chapter 5 that **chromosomes** are structures in the cell that contain the genetic information that is passed on from one generation of cells to the next. The word

chromosome, meaning colored body, was derived from the fact that when a dye was added to the cell, the chromosomes picked up the color of the dye and were easily seen through the light microscope during cell division. Unfortunately, chromosomes are not visible in most cells except during mitosis.

Chromosomes contain the genetic information in the form of DNA. In prokaryotic cells, the chromosomes are made up of long circular molecules of DNA. In eukaryotic cells, the chromosomes are made up of distinct lengths of DNA. The cells of every organism contain a specific number of chromosomes. Human cells, for example, contain 46 chromosomes; goldfish cells contain 94 chromosomes. See Figure 8–7.

Organism	Chromosome Number
Ameba	50
Carrot	18
Cat	32
Chimpanzee	48
Dog	78
Earthworm	36
Goldfish	94
Human	46
Lettuce	18

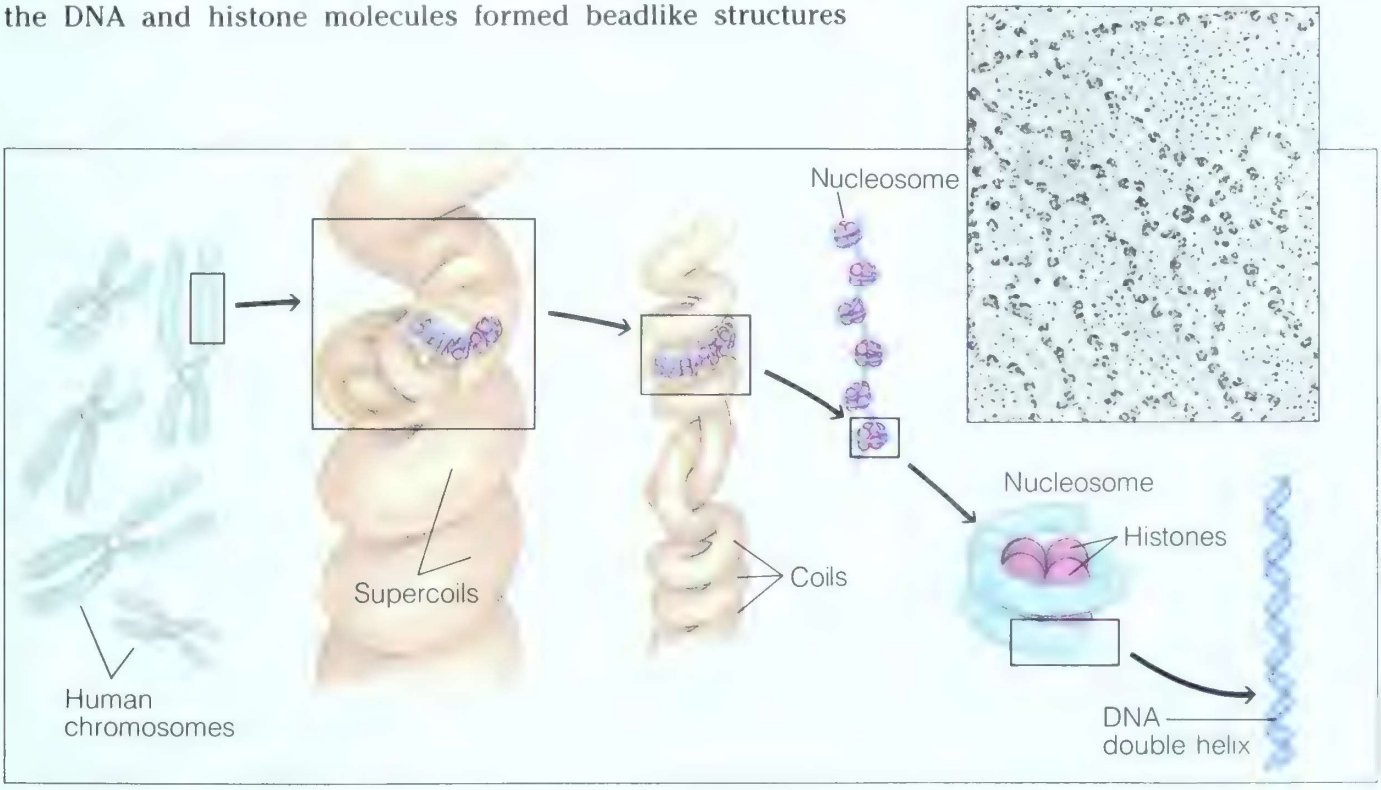
Figure 8–7 *Which organism's chromosome number is closest to that of an ameba?*

COMPOSITION OF CHROMATIN Chromosomes are made up of a material called **chromatin** (KROH-muh-tihn). During the period of time between cell divisions, chromatin forms condensed and dispersed regions. See Figure 8–6. During the early stages of mitosis, the chromatin condenses and the chromosomes become visible.

Chromatin is composed of DNA and protein. Much of this protein is involved in the folding of DNA so that it can fit within the nucleus. This is an important job because the DNA double helix that makes up a chromosome is much longer than the chromosome itself. In fact, the total length of DNA in a typical human chromosome is about 10,000 times the length of the chromosome! How does all that DNA fit into the chromosome?

In 1973, the American scientists Don Olins, Ada Olins, and Christopher Woodcock discovered that the chromosomes' DNA was coiled around special proteins called histones. Together, the DNA and histone molecules formed beadlike structures

Figure 8–8 *Chromosomes contain highly coiled and supercoiled strands of DNA. Notice that a small part of the supercoil is made up of nucleosomes (inset).*



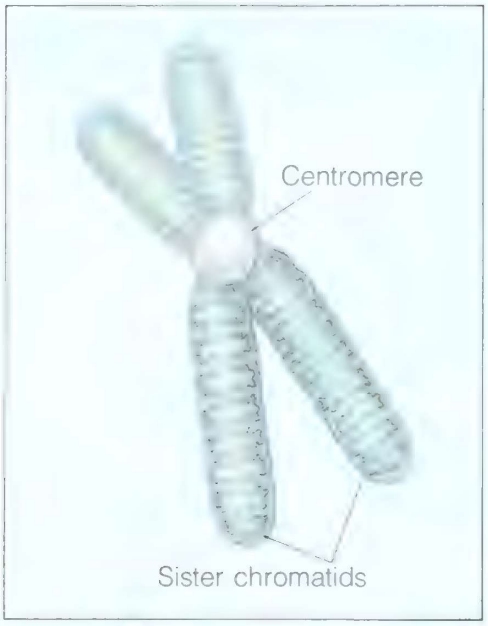




Figure 8–9 *The diagram of a chromosome shows that it consists of two chromatids attached by means of a centromere. A human chromosome is shown as it appears through an electron microscope.*

called nucleosomes (NOO-klee-oh-sohmz). The nucleosomes interact with one another to form a thick fiber, which is shortened by a system of loops and coils. The result is the tightly packed chromosomes that are seen through a light microscope in dividing cells. The tight packing of nucleosomes may be necessary in order to form a compact structure that can be separated during mitosis.

CHROMOSOME STRUCTURE After DNA replication, the chromosomes become visible by condensing. This is the beginning of mitosis. The chromosome contains two **chromatids** (KROH-muh-tihdz), or identical parts, which are often called sister chromatids. Each pair of chromatids is attached at an area called the **centromere** (SEHN-troh-mihr). Centromeres are usually located near the middle of the chromatids, although some centromeres lie near the ends of the chromatids. A human cell entering mitosis contains 46 chromosomes, each of which consists of two chromatids.

The Cell Cycle

At one time biologists described the life of a cell as one mitosis after another separated by an "in-between" period of growth called interphase. We now know more and can represent some of the events in the life of a cell by using a concept known as the **cell cycle**. The cell cycle is the period from the beginning of one mitosis to the beginning of the next. **During a cell cycle, a cell grows, prepares for division, and divides to form two daughter cells, each of which begins the cycle anew.**

The cell cycle includes mitosis, a period of active division, and interphase, a period of nondivision during which other processes take place. It also includes a process in which cytoplasm and its contents divide forming the two daughter cells. You will learn about this process, called cytokinesis, later in this section. Mitosis is represented as the M phase. During mitosis, the nucleus divides into two nuclei. Interphase is usually divided into three phases: G_1 (gap 1), S (DNA synthesis), and G_2 (gap 2). G_1 and G_2 were once thought to be gaps but are now known as periods of growth and activity.

The time required to complete a single turn of the cycle is the time required for a cell to reproduce itself. Not all cells move through the cell cycle at the same rate. In the human body, most muscle cells and nerve cells do not divide at all once they have developed. In contrast, the cells that line the organs of the digestive system grow and divide rapidly. In fact, these cells may pass through a complete cycle every six hours.

Interphase

Within the normal cell cycle, **interphase**, or the period between cell divisions, can be quite long, whereas the actual divi-

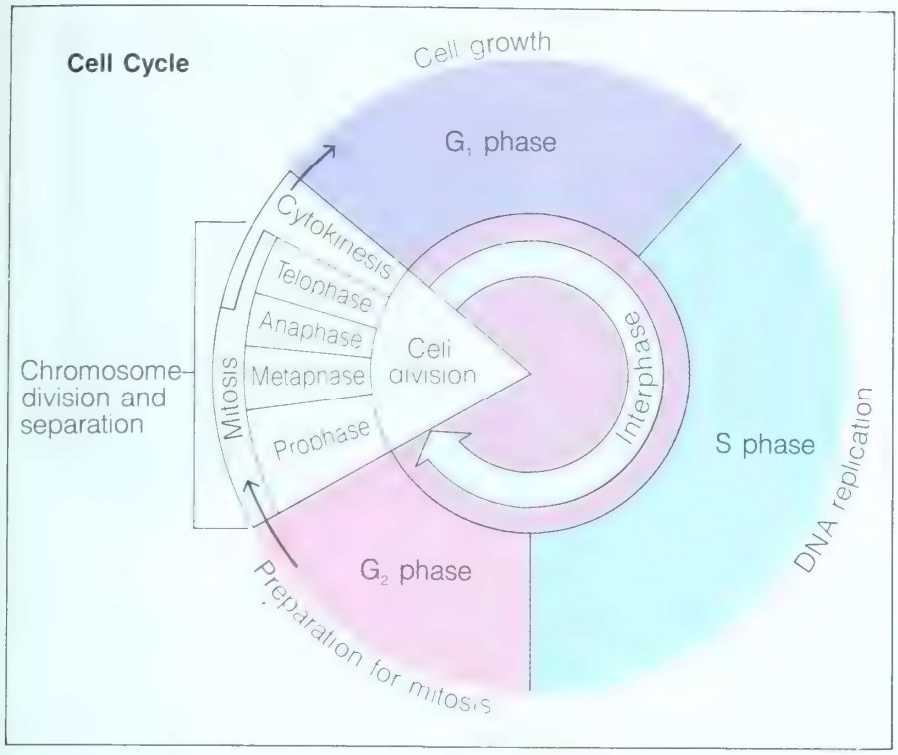


Figure 8–10 *The cell cycle includes mitosis, cytokinesis, and the three phases of interphase. What are the names of the three phases of interphase?*

sion of the cell takes place quickly. As you read, interphase is divided into three phases: G_1, S, and G_2. Each of these phases is characterized by specific events.

The G_1, or gap 1, phase is a period of activity in which cellular growth and development take place. G_1 is followed by the S, or DNA synthesis, phase. During this phase, DNA replication takes place. Several proteins, including those associated with the chromosomes, are synthesized during the S phase.

Finally, when the S phase is completed, the cell enters the G_2, or gap 2, phase. This phase is usually the shortest of the three phases of interphase. The G_2 phase involves the synthesis of organelles and materials required for cell division.

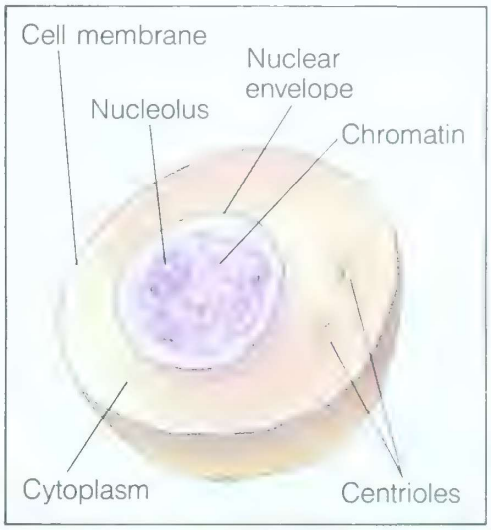
During interphase, the nucleus is active in synthesizing messenger RNA in order to direct cellular activities. Although the cell seems to be "quiet" during interphase, it is actually a period of intense activity. Proteins are made; DNA is copied; ATP is made and utilized. In multicellular organisms, cells that are specialized for jobs such as secretion, movement, and signaling do most of their work during interphase.

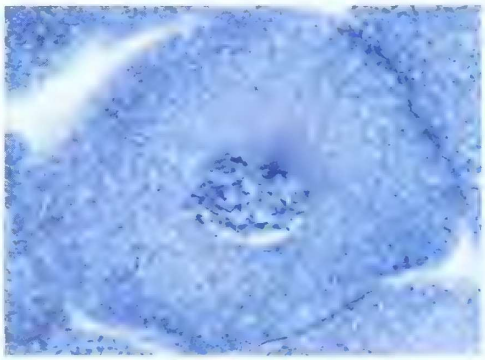
Prophase

Recall that mitosis, or the M phase of the cell cycle, is the process by which the cell's nucleus divides into two nuclei. Mitosis may last anywhere from a few minutes to several days, depending on the type of cell. **Mitosis is divided into four phases: prophase, metaphase, anaphase, and telophase.**

The first phase of mitosis, **prophase**, is the longest phase, frequently taking 50 to 60 percent of the total time required to

Figure 8–11 *Interphase is the part of the cell cycle that occurs before mitosis can take place. Notice that the chromatin in the nucleus appears as an indistinct mass of threadlike structures.*





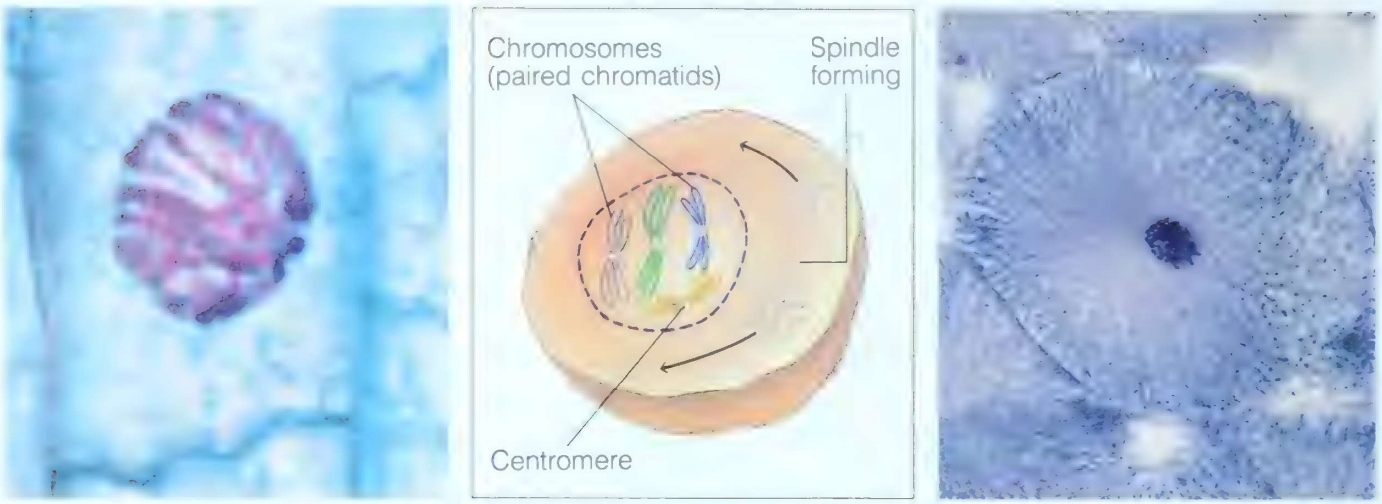


Figure 8–12 *During prophase, the first stage of mitosis, the chromatin condenses into distinct chromosomes and the nucleolus disappears. The photomicrographs show prophase in a plant cell (left) and an animal cell (right).*

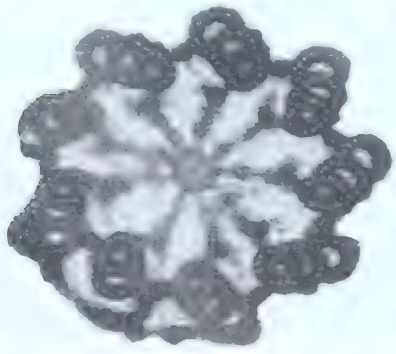
complete mitosis. The first clue that prophase is beginning is the appearance of chromosomes. Chromosomes become visible as a result of the condensing and coiling of the yarnlike chromatin. Under a light microscope, each chromosome is seen as two identical chromatids lying side by side. Recall that the area where two chromatids are attached to each other is called the centromere.

During prophase, the **centrioles**, two tiny structures located in the cytoplasm near the nuclear envelope, separate from each other and take up positions on the opposite sides of the nucleus. Centrioles are structures that contain tubulin, a microtubule protein.

During prophase, the condensed chromosomes become attached to fibers in the **spindle** at a point near the centromere of each chromatid. The spindle, a meshlike structure that helps move the chromosomes apart, develops from the centrioles. Recall from Chapter 5 that plant cells do not contain centrioles. However, plant cells form a spindle that is almost identical in structure to that of animal cells. Like the centrioles, the fibers of the spindle are composed of microtubules.

Near the end of prophase, the coiling of the chromosomes becomes tighter. In addition, the nucleolus disappears and the nuclear envelope breaks down.

Figure 8–13 *Notice the ringlike shape of a centriole in this electron micrograph. Centrioles are cellular structures that are found near the nuclear envelope of an animal cell and play a part in mitosis.*



Metaphase

As prophase ends, **metaphase**, or the second phase of mitosis, begins. Metaphase is the shortest phase of mitosis. It often lasts only a few minutes.

During metaphase, the chromosomes line up across the center, or equator, of the cell. Microtubules connect the centromere of each chromosome to the poles of the spindle. Because of their starlike arrangement around the poles of the spindle, these microtubules are called asters, which is the Greek word for star. See Figure 8–14.

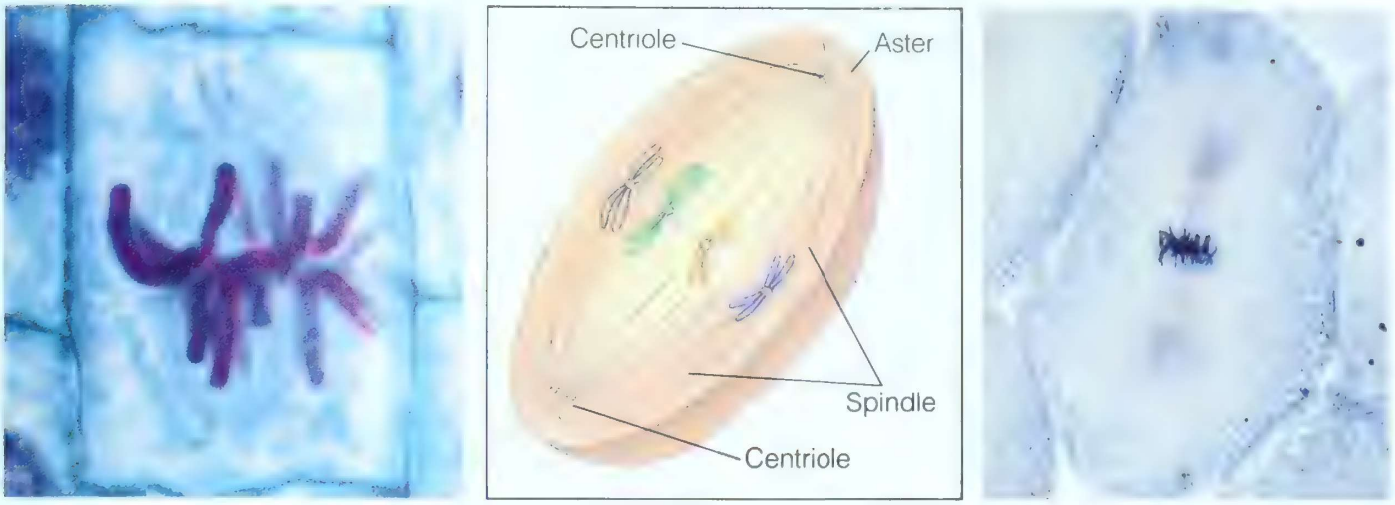


Figure 8–14 *Notice how the chromatid pairs line up across the center of the plant cell (left) and the animal cell (right). This arrangement of chromatids marks metaphase, or the second phase of mitosis.*

Anaphase

Anaphase, the third phase of mitosis, begins when the centromeres that join the sister chromatids split. This action causes the sister chromatids to separate, becoming individual chromosomes. As the two groups of chromosomes separate, the spindle itself grows longer. The chromosomes continue to move until they have separated into two groups near the poles of the spindle. See Figure 8–15. Anaphase ends when the movement of chromosomes stops.

For years, cell biologists have wondered what provides the force that separates the chromosomes during anaphase. Surprisingly, the answer is still not known. There is evidence that some proteins form bridges between the microtubules extending from opposite poles and use energy from ATP to push each microtubule toward its own pole. However, there is also a suggestion that the rapid assembly and breakdown of microtubules may cause chromosome movement. For the time being, this remains one of the cell's most intriguing riddles.

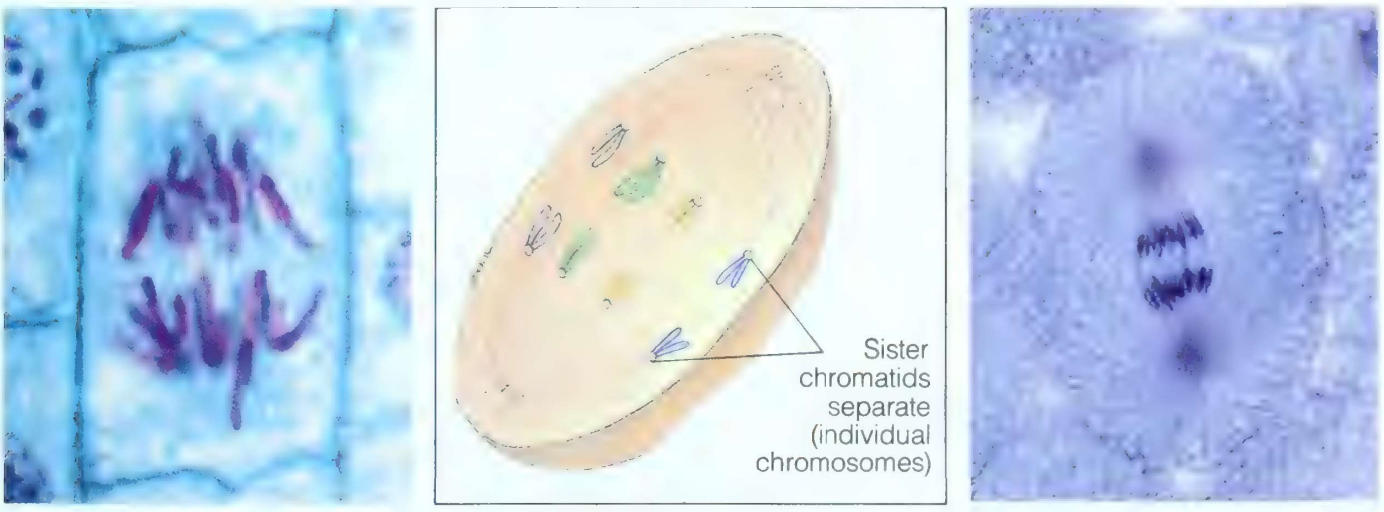


Figure 8–15 *Anaphase, the third phase of mitosis, begins when the centromeres that link the sister chromatids split, allowing each chromatid to become an individual chromosome. Notice that centrioles are present in the animal cell (right) but not in the plant cell (left).*

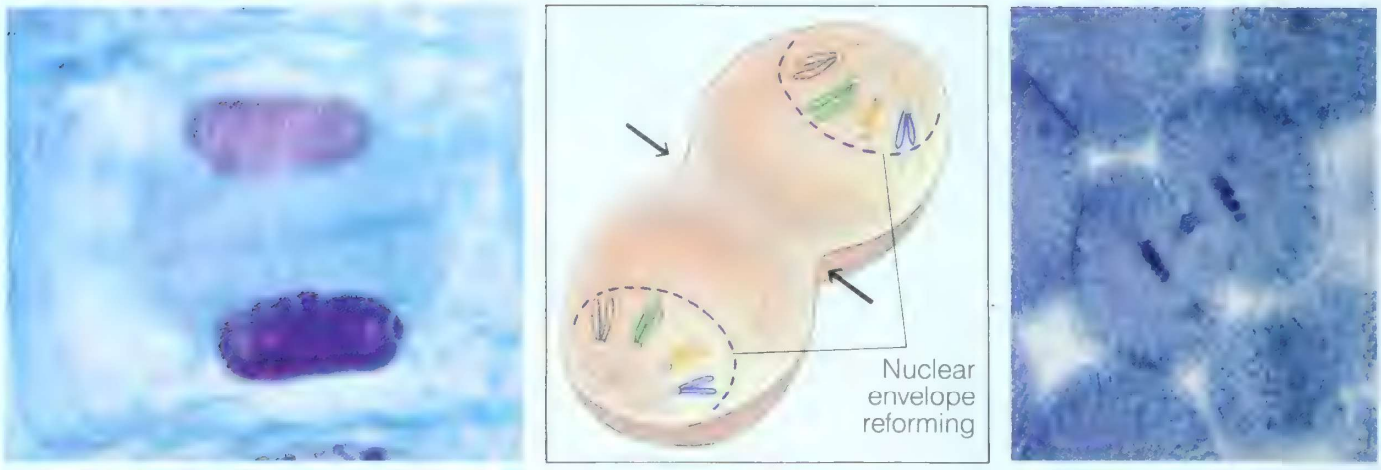


Figure 8–16 *In the final phase of mitosis, called telophase, two new daughter cells begin to form. Notice the two distinct groups of chromosomes in the plant cell (left) and in the animal cell (right).*

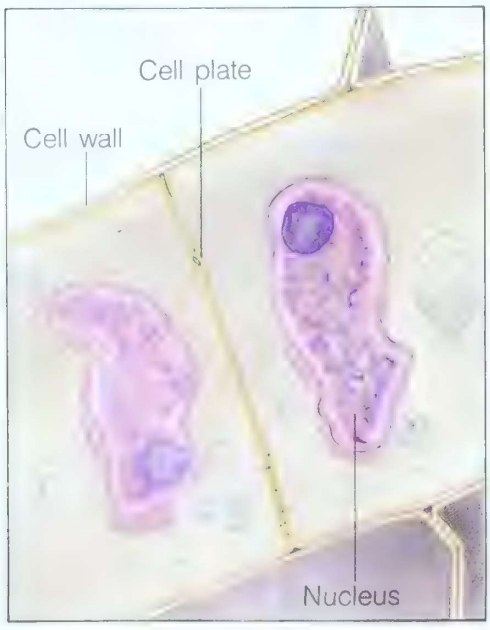
Telophase

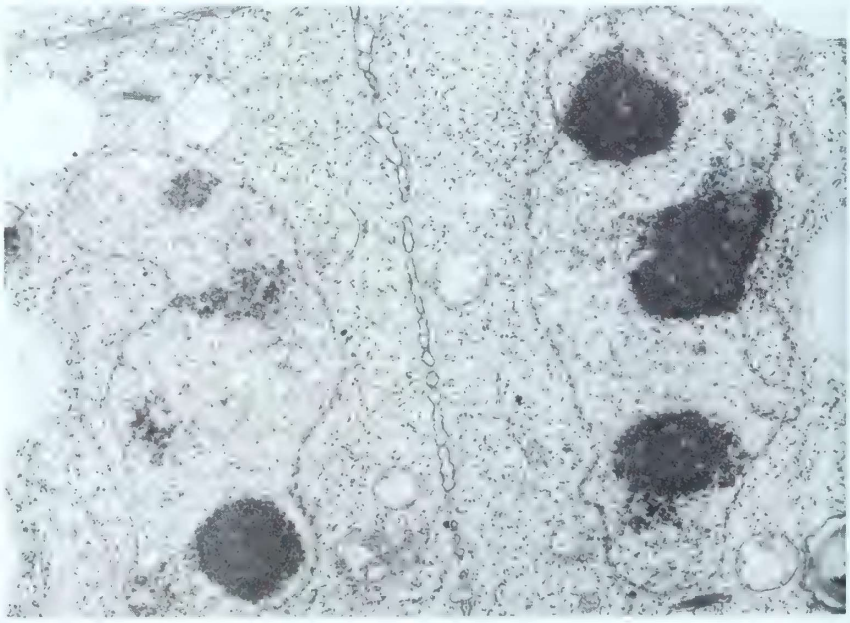
Telophase is the final phase of mitosis. The chromosomes, which have been distinct and condensed all during mitosis, now begin to uncoil into a tangle of chromatin. This occurs in the two regions where the nuclei of the daughter cells will form. The nuclear envelope reforms around the chromatin, the spindle begins to break apart, and a nucleolus becomes visible in each daughter nucleus. Mitosis is now complete. However, the process of cell division is not.

Figure 8–17 *Cytokinesis is the division of the cytoplasm and its contents into two individual daughter cells. In plant cells, the cytoplasm is divided by a cell plate. The large dark structures in the electron micrograph are the chromosomes.*

Cytokinesis

As a result of mitosis, two nuclei—each with a duplicate set of chromosomes—are formed. Now it remains for the cytoplasm of the cell to divide. This is accomplished as cytokinesis quickly follows mitosis. Cytokinesis, you will recall, is the division of the cytoplasm into two individual cells.





A Useful Poison

The meadow saffron, *Colchicum autumnale*, is a flowering plant that grows wild in the meadowlands of England, Ireland, and middle and southern Europe. Its lovely flowers, which range in color from lavender to white, bloom in the fall. But the meadow saffron's flowers are deceiving. Though beautiful, the colorful meadow saffron contains a poison known as colchicine (KAHL-chih-seen).



In the laboratory, however, colchicine is a very useful drug. Colchicine stops cell division, making it important in the study of chromosomes. When colchicine is added to a culture of growing cells, it attaches to the microtubules in the spindle and causes them to disintegrate. As a result, the spindle is destroyed and mitosis is stopped at metaphase. When the cells are examined under a light microscope, each chromosome is visible as a pair of chromatids that are joined at the centromere.

Laboratory technicians routinely use colchicine because it enables them to count and measure chromosomes. Cell biologists use the drug as a method of studying the assembly and disassembly of microtubules. Scientists were able to find an important use for a very poisonous drug.

Cytokinesis can take place in a number of ways. In most animal cells, the cell membrane moves inward until the cytoplasm is pinched into two nearly equal parts, each part containing its own nucleus and cytoplasmic organelles. In plants, a structure known as the cell plate forms midway between the divided nuclei. The cell plate gradually develops into a separating membrane. A cell wall begins to appear in the cell plate.

8–2 SECTION REVIEW

1. What is mitosis? Cytokinesis?
2. Describe the structure of a chromosome.
3. Name the three main stages of the cell cycle.
4. Briefly describe the three phases of interphase.
5. What are the four phases of mitosis?

LABORATORY INVESTIGATION

OBSERVING ONION ROOT TIPS

PROBLEM

What are the stages of the cell cycle in a plant cell?

MATERIALS *(per group)*

onion root tips	timer or clock with second hand
safety goggles	2 glass slides
metric ruler	2 medicine droppers
scalpel	toluidine blue
ethanol-acetic acid fixative	probe
3 50-mL beakers	paper towels
glass-marking pencil	coverslip
hydrochloric acid	pencil with eraser
forceps	microscope

PROCEDURE

1. Label the three 50-mL beakers with the glass-marking pencil as follows: fixative, hydrochloric acid, water. Put on your safety goggles and add 10 mL of each liquid to the appropriately labeled beaker. **CAUTION:** *Because acids can burn the skin, handle them with care.* Place the beaker containing the water aside for now.
2. Using the forceps, place the onion root tips in the hydrochloric acid for 4 minutes.
3. After 4 minutes, use the forceps to remove the root tips from the hydrochloric acid. Place them in the fixative for 4 minutes.
4. After 4 minutes, use the forceps to remove the root tips from the fixative and place them on a clean glass slide. Holding the root tips with the forceps, use the scalpel to cut off about 1 mm from each root tip. **CAUTION:** *Be careful when using a scalpel.* Discard the rest of the root tips.
5. Using the forceps, place one root tip on a clean glass slide and then place the glass slide on a paper towel.
6. With a medicine dropper, place a few drops of toluidine blue on the root tip. Allow the toluidine blue to remain on the root tip for 2 minutes. After 2 minutes, use a paper towel to absorb the excess liquid.
7. Using a clean medicine dropper, place two drops of water on the root tip. Cover it with a coverslip. Use the probe to lower the coverslip over the slide.
8. Place a paper towel over the slide and with the eraser end of the pencil gently press down on the area covered by the coverslip. This will squash the root tip. **CAUTION:** *Do not press so hard as to break the coverslip or the glass slide.*
9. With the microscope, examine the onion root tip under low power to find cells in various stages of the cell cycle. (**Note:** If you cannot clearly distinguish the stages of the cell cycle, repeat steps 5 through 9 using another root tip.)
10. After you have located the various stages of the cell cycle under low power, switch to high power. Draw and label a cell from each stage of the cell cycle. Be sure to identify each stage.

OBSERVATIONS

1. Describe what is happening in each stage of the cell cycle.
2. What stage occurs most frequently?
3. How is interphase different from the other stages?
4. What is the color of the chromosomes? Of other cell structures?

ANALYSIS AND CONCLUSIONS

1. What is the purpose of the toluidine blue?
2. In which area of the onion root tip do most of the cells appear to be undergoing mitosis?
3. How can you tell that mitosis is a continuous process?
4. Do some stages of the cell cycle occur more frequently than others? Identify the stage(s) and explain why.

STUDENT STUDY GUIDE

SUMMARIZING THE CONCEPTS

The key concepts in each section of this chapter are listed below to help you review the chapter content. Make sure you understand each concept and its relationship to other concepts and to the theme of this chapter.

8–1 Cell Growth

- Living things grow because they produce more and more cells.
- As a cell increases in size, its volume increases at a faster rate than its surface area.
- The amount of material entering and leaving a cell and the amount of DNA in the nucleus help to limit the size to which a cell can grow.
- Cell division is the process whereby the cell divides into two daughter cells.
- Cancer is a disorder in which some cells have lost the ability to control their rate of growth.

8–2 Cell Division: Mitosis and Cytokinesis

- Cell division in eukaryotic cells occurs in two main stages: mitosis and cytokinesis.
- Mitosis is the process by which the nucleus of the cell is divided into two nuclei, each with the same number and kinds of chromosomes as the parent cell.
- Cytokinesis is the process by which the cytoplasm divides, forming two distinct cells.
- Chromosomes are cellular structures that contain the genetic information that is passed on from one generation to the next. These structures are made up of chromatin, which is composed of DNA and protein.
- The two identical parts of a chromosome, called chromatids, are attached to each other at a centromere.
- During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells, which repeat the cycle.
- The cell cycle consists of three main stages: mitosis, interphase, and cytokinesis.
- Interphase, the period between cell divisions, is divided into three phases: G_1, S, and G_2.
- Mitosis has four phases: prophase, metaphase, anaphase, and telophase.
- Cytokinesis ends the process of cell division. In animal cells, the cell membrane moves inward until the cytoplasm is pinched in two, each half containing its own nucleus and cytoplasmic organelles. In plant cells, a cell plate forms midway between the divided nuclei, then a cell wall appears in the cell plate.

REVIEWING KEY TERMS

Vocabulary terms are important to your understanding of biology. The key terms listed below are those you should be especially familiar with. Review these terms and their meanings. Then use each term in a complete sentence. If you are not sure of a term's meaning, return to the appropriate section and review its definition.

8–1 Cell Growth

cell division

8–2 Cell Division: Mitosis and Cytokinesis

mitosis	chromatid	prophase	anaphase
cytokinesis	centromere	centriole	telophase
chromosome	cell cycle	spindle	
chromatin	interphase	metaphase	

CHAPTER REVIEW

CONTENT REVIEW

Multiple Choice

Choose the letter of the answer that best completes each statement.

1. Uncontrolled cell division is known as
   a. cancer. c. cytokinesis.
   b. mitosis. d. growth.
2. Chromatids are held together by a (an)
   a. centriole. c. spindle.
   b. centromere. d. aster.
3. Each chromosome strand is called a (an)
   a. centriole. c. chromatid.
   b. centromere. d. aster.
4. A cell has 12 chromosomes. How many chromosomes will each daughter cell have?
   a. 24 c. 12
   b. 6 d. 4
5. The phase of mitosis that is characterized by the lining up of chromosomes along the center of the cell is known as
   a. prophase. c. anaphase.
   b. metaphase. d. telophase.
6. During normal mitosis, which occurs first?
   a. spindle formation
   b. growth and development of daughter cells
   c. chromosome duplication
   d. cytoplasmic division of the cell
7. A cell that is undergoing mitosis is examined with a light microscope. The cell is most likely an animal cell if the
   a. chromosome pairs separate from each other.
   b. chromosomes twist about each other.
   c. nucleoli disappear.
   d. centrioles migrate.
8. A structure found during plant cell division that is not found during animal cell division is a
   a. centromere. c. cell membrane.
   b. cell plate. d. spindle.

True or False

Determine whether each statement is true or false. If it is true, write "true." If it is false, change the underlined word or words to make the statement true.

1. As a cell increases in size, its volume increases at a faster rate than its surface area.
2. As a result of mitosis, a cell having 10 chromosomes gives rise to two cells, each of which contains 20 chromosomes.
3. DNA replication occurs during prophase.
4. Animal cells contain centrioles.
5. Interphase is usually divided into three phases: G_1, S, and G_2.
6. Anaphase is the first phase of mitosis.
7. During prophase, the centrioles separate from each other and take up positions on the opposite sides of the nucleus.
8. In animal cells, a cell plate forms midway between the divided nuclei.

Word Relationships

A. *In each of the following sets of terms, three of the terms are related. One term does not belong. Determine the characteristic common to three of the terms and then identify the term that does not belong.*

1. anaphase, interphase, metaphase, telophase
2. chromatid, centromere, chromosome, centriole
3. spindle, aster, microtubule, chromosome
4. cell division, cytokinesis, mitosis, aster

B. *Replace the underlined definition with the correct vocabulary word.*

5. The structures in the cell that contain the genetic information are not visible in most cells except during mitosis.
6. The first phase of mitosis begins when the chromsomes become visible.
7. The meshlike structure that helps move the chromosomes apart develops from the centrioles.
8. In the final phase of mitosis, the chromosomes are found at opposite poles of the cell.

CONCEPT MASTERY

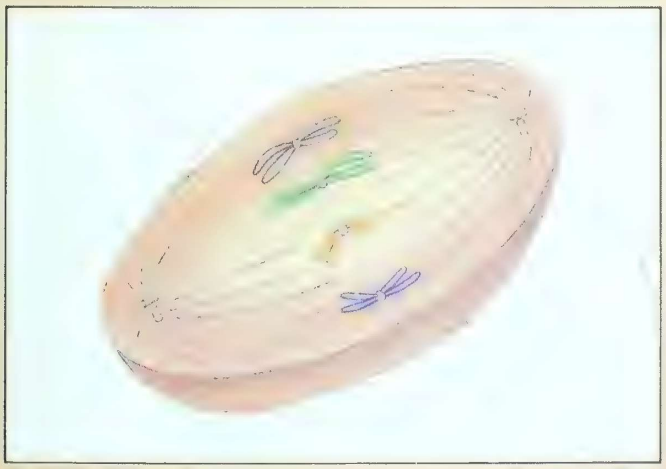
Use your understanding of the concepts developed in the chapter to answer each of the following in a brief paragraph.

1. How do living things grow? What are some factors that limit the growth of a cell?
2. Why do cells divide?
3. Distinguish between chromatin, chromosomes, chromatids, and centromeres.
4. List and describe the phases of the cell cycle.
5. What occurs during interphase? How are interphase and the cell cycle related?
6. Identify and describe the phases of mitosis.
7. Distinguish between cell division in an animal cell and cell division in a plant cell.
8. Why is cell division so complicated in eukaryotic organisms?
9. Compare spindles and asters.

CRITICAL AND CREATIVE THINKING

Discuss each of the following in a brief paragraph.

1. **Relating facts** The diagram below shows a phase of mitosis. Identify the phase of mitosis and indicate whether the cell is from a rose or a tiger. Give a reason for your answer.



2. **Making calculations** A cell is 4μm long, 3μm wide, and 3μm high. Find the ratio of volume to surface area.
3. **Applying concepts** Is mitosis occurring in your body right now? If so, where? Explain your answer.
4. **Relating concepts** After muscle and nerve cells form in the body, they seldom undergo mitosis. Explain how this affects the human body.
5. **Relating cause and effect** What structure within the cell is most likely to play a major role in the development of generations of cancer cells? Explain your answer.
6. **Using the writing process** Suppose you were small enough to hitch a ride on a chromosome located in a cell that divides by mitosis. Describe what you would see happening during this process.