CHAPTER 11

Cell Growth and Division

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HS-ETS1-1, HS-LS1-4

CASE STUDY

Will stem cells change the future of healing?

More than 50 years ago, a young British scientist named John Gurdon carried out a revolutionary experiment. He transferred the nucleus from an adult frog cell into the cytoplasm of a frog egg cell. The result was that the cytoplasm "reprogrammed" the nucleus. The transformed cell developed first into an embryo and then into a fully functional tadpole.

Most cells in an adult organism are specialized to carry out specific tasks, such as carrying oxygen, producing digestive enzymes, or fighting disease. Gurdon's work showed that even adult cells could be changed back into the unspecialized embryonic "stem cells" that have the potential to grow into nearly any cell type.

Today, many physicians are beginning to apply the biological principle that Gurdon demonstrated in order to replace cells damaged by injury or disease. In so doing, they have begun to establish a new field called regenerative medicine. They hope that transplants of stem cells taken from embryos, from adult tissues like bone marrow, or from reprogrammed adult cells will make it possible to treat patients with failing eyesight, arthritic joints, or diseased livers. In the future, stem cells could also be used to treat heart attacks and strokes. If stem cells could repair an injured spinal cord, a paralyzed person might walk again.

Experts agree on the many potential benefits of stem cell therapies. However, there also are dangers. Injected stem cells may not develop into the cell types they are intended to replace. They also might damage neighboring tissues or produce tumors. In many cancerous tumors, the cells are undifferentiated and resemble stem cells in some ways. The Food and Drug Administration (FDA) and other government agencies are considering whether stem cell clinics should go through an approval and regulatory process, such as that required for medicines and drugs.

Physicians, researchers, and patients are faced with many questions about stem cells. Are the benefits of stem cell therapies worth the costs or the risks? How closely should the therapies be regulated? Who should make the important decisions?

Throughout this chapter, look for connections to the CASE STUDY to help you answer these questions.

Cell division in an animal cell.
(False-color LM: 9000×)

LESSON 11.1

Cell Growth, Division, and Reproduction

Eaglets will grow into adult eagles.

KEY QUESTIONS

- *What are some of the difficulties a cell faces as it increases in size?*
- *How do asexual and sexual reproduction compare?*

HS-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

VOCABULARY

cell division
asexual reproduction
sexual reproduction

READING TOOL

As you read, identify the similarities and differences between sexual and asexual reproduction. Include the advantages and disadvantages of each in the Venn diagram in your **Biology Foundations Workbook.**

When a living thing grows, what happens to its cells? Does an organism get larger because each cell increases in size or because it produces more cells? In most cases, living things grow by producing more cells. What is there about growth that requires cells to divide and produce more of themselves?

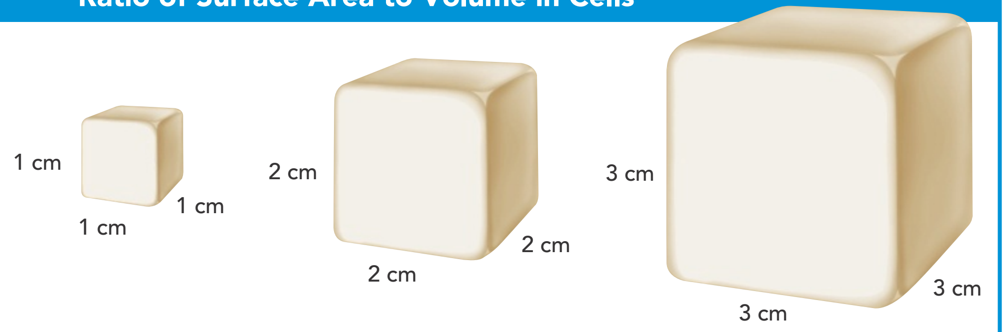
Limits to Cell Size

Each of us begins life as a single cell. By the time we are adults, however, that single cell has grown and divided so many times that the average human body contains nearly 40 trillion cells. To impress your math teacher, you might want to calculate how many rounds of cell division would be required to go from one cell to 40 trillion (40×10^{12}). The answer might surprise you!

Cells can grow by increasing in size, but eventually, most cells divide after growing to a certain point. There are two main reasons that cells divide rather than continuing to grow. ***The larger a cell becomes, the less efficient it is in moving nutrients and waste materials across its cell membrane. In addition, as a cell grows, it places increasing demands on its own DNA.***

A Problem of Size All cells are connected to the outside world through their cell membranes. To stay alive, a cell must allow food, oxygen, and water to enter through its cell membrane. Waste products have to leave the cell in the same way. The rate at which this exchange takes place depends on the surface area of the cell, which is the total area of its cell membrane. The rate at which food and oxygen are used up and wastes are produced depends on a cell's volume. As a cell gets larger, these rates increase, as does its surface area. However, volume and surface area do not increase at the same rate, and this is a key reason that cells must eventually divide rather than continue to grow without limit.

Ratio of Surface Area to Volume in Cells



Surface Area (length × width) × 6 sides	1 cm × 1 cm × 6 = 6 cm^2	2 cm × 2 cm × 6 = 24 cm^2	3 cm × 3 cm × 6 = 54 cm^2
Volume (length × width × height)	1 cm × 1 cm × 1 cm = 1 cm^3	2 cm × 2 cm × 2 cm = 8 cm^3	3 cm × 3 cm × 3 cm = 27 cm^3
Ratio of Surface Area to Volume	6 / 1 = 6 : 1	24 / 8 = 3 : 1	54 / 27 = 2 : 1

Figure 11-1

Ratio of Surface Area to Volume

As the length of the sides of the cube increases, the cube's volume increases more than its surface area.

Ratio of Surface Area to Volume Imagine a cell that is shaped like a cube. The formula for area ($l \times w$) is used to calculate the surface area. The formula for volume ($l \times w \times h$) is used to calculate the amount of space inside. By using a ratio of surface area to volume, you can see how the size of the cell's surface area grows compared to its volume.

Notice that for a cell with sides that measure 1 cm in length, the ratio of surface area to volume is 6/1 or 6 : 1. Increase the length of the cell's sides to 3 cm, and the ratio becomes 54/27 or 2 : 1. As you can see from the calculations shown in **Figure 11-1**, surface area does not increase as fast as volume does. For a growing cell, this decrease in the relative amount of cell membrane available creates serious problems. The largest cells, such as the one shown in **Figure 11-2**, use unusual shapes or structures to maintain the ratio.

INTERACTIVITY

Investigate how and why cells are limited in how large they can grow.

READING CHECK **Infer** If a cell keeps growing, why must it eventually divide?

Figure 11-2

A Long Cell

Most single-celled organisms are too small to see without a microscope. However, the cell that makes up *Caulerpa taxifolia*, a type of algae, can grow up to 30 cm (12 in.). The cells of *Caulerpa taxifolia* are the largest known living cells of any organism!

Visual Analogy

Figure 11-3

Growing Pains

Lots of growth can mean lots of trouble—both in a town and in a cell. **Use Analogies** How could cell growth create a problem that is similar to a traffic jam?

READING TOOL

Relate cause and effect to explain why cell size is limited.

Traffic Problems Compare a growing cell to a small town with a two-lane main street running through it, such as the one shown in **Figure 11-3**. As the town grows, more and more traffic begins to clog the main street. Moving materials in and out of town becomes increasingly difficult. Businesses cannot get the goods they need and trash piles up because garbage trucks are stuck in traffic jams. In the same way, if a cell were to get too large, it would be more difficult to get sufficient amounts of oxygen and nutrients in and waste products out.

Information Overload Many cells face another problem as they grow. Living cells store critical information in a molecule known as DNA. As a cell grows, that information is used to build the molecules needed for cell growth. But as a cell increases in size, its "library" of information in DNA remains the same. If a cell were to grow too large, an "information crisis" might occur. A growing town with an overused library that no longer serves its needs might decide to build a new library. In the case of a cell, it might be time to make a duplicate copy of that DNA and divide it between two new cells.

Cell Division

The process by which a cell divides into two new daughter cells is called **cell division**. Before cell division can occur, its DNA must be copied, or replicated. DNA replication solves the problem of information overload because each daughter cell gets one complete copy of genetic information. Cell division also solves the problem of increasing size by reducing cell volume. This results in an increase in the ratio of surface area to volume for each daughter cell, allowing for a more efficient exchange of materials between the cell and its environment.

READING CHECK **Summarize** What potential problems of a cell are solved by cell division?

Cell Division and Reproduction

All living things must be able to reproduce by forming new individuals. For an organism composed of just one cell, cell division itself can serve as a perfectly good form of reproduction. You don't have to meet someone else, conduct a courtship, or deal with rivals. All you have to do is to divide, and *presto*—there are two of you!

Asexual Reproduction For many single-celled organisms, such as the bacterium in **Figure 11-4**, cell division is their only form of reproduction. The process can be relatively simple, efficient, and effective, enabling populations to increase in number very quickly. In most cases, the two cells produced by cell division are genetically identical to the cell that produced them. This kind of reproduction is called **asexual reproduction**. ***The production of genetically identical offspring from a single parent is known as asexual reproduction.***

Asexual reproduction also occurs in many multicellular organisms—even in such organisms as plants that can reproduce sexually. The small bud growing off the hydra will eventually break off and become an independent organism, an example of asexual reproduction in an animal. Each of the small shoots or plantlets on the tip of the kalanchoe leaf may also grow into a new plant.

Sexual Reproduction Unlike asexual reproduction, in which cells separate to form a new individual, **sexual reproduction** involves the fusion of two reproductive cells formed by each of two parents. ***Offspring produced by sexual reproduction inherit some of their genetic information from each parent.*** Most animals and plants reproduce sexually, as do many single-celled organisms. You will learn more about the special form of cell division that produces these reproductive cells in Chapter 12.

INTERACTIVITY

Explore the reproductive strategies of algae.

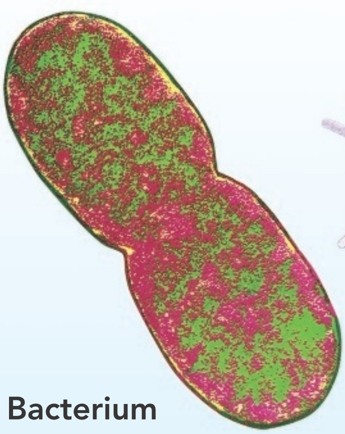
BUILD VOCABULARY

Prefixes The prefix *a-* in **asexual** means "without." Asexual reproduction is reproduction without the fusion of reproductive cells.

Figure 11-4

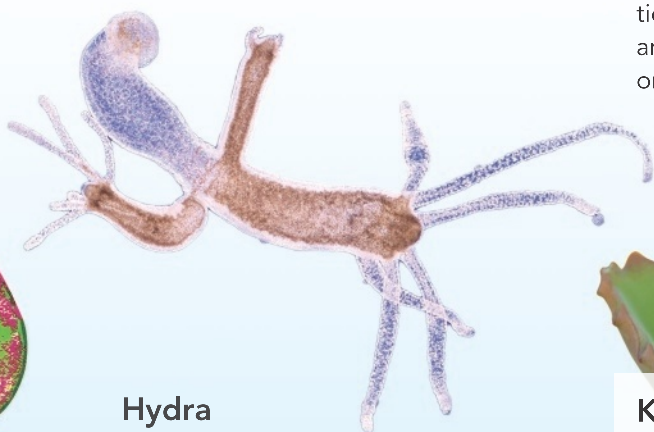
Asexual Reproduction

Cell division leads to reproduction in single-celled organisms and some multicellular organisms.



Bacterium

Prokaryotes undergo a form of asexual reproduction known as binary fission, in which the cell splits in two after the chromosome replicates.
(False-color TEM: 34,000×)



Hydra

Hydras reproduce by budding. An offspring starts off as a lump on its parent. This bud grows, develops tentacles, and eventually separates from its parent. (LM: 16×)

Kalanchoe

Plants reproduce asexually through vegetative propagation. The plantlets at the edge of this kalanchoe leaf will eventually drop off and grow on their own.

INTERACTIVITY

Figure 11-5

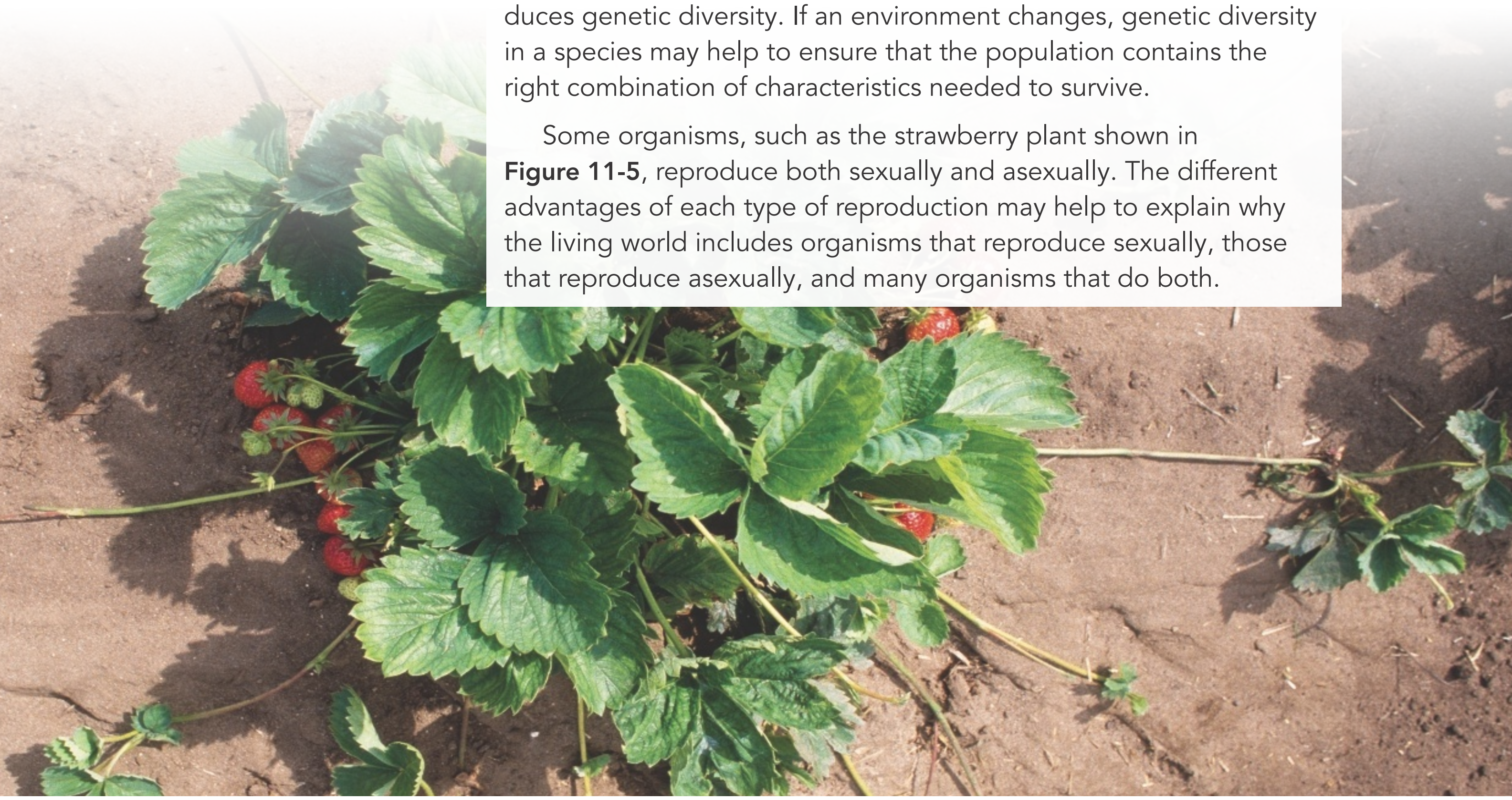
Asexual and Sexual Reproduction

The runners, or plantlets, growing off this strawberry plant are the result of asexual reproduction. The strawberries, which form from the flowers, are the result of sexual reproduction.

Comparing Asexual and Sexual Reproduction Each type of reproduction has its own advantages and disadvantages in terms of survival strategies. For many single-celled organisms, asexual reproduction provides clear advantages. When conditions are right, these organisms can reproduce quickly, enabling them to compete successfully with other organisms. However, a lack of genetic diversity can become a disadvantage when conditions change in ways that do not fit the characteristics of an organism.

Sexual reproduction involves finding a mate and then allowing for the growth and development of offspring. This may require more time than asexual reproduction. However, this can be an advantage for species that live in environments where seasonal changes affect weather conditions and food availability. Sexual reproduction produces genetic diversity. If an environment changes, genetic diversity in a species may help to ensure that the population contains the right combination of characteristics needed to survive.

Some organisms, such as the strawberry plant shown in **Figure 11-5**, reproduce both sexually and asexually. The different advantages of each type of reproduction may help to explain why the living world includes organisms that reproduce sexually, those that reproduce asexually, and many organisms that do both.



HS-LS1-4

LESSON 11.1 Review

KEY QUESTIONS

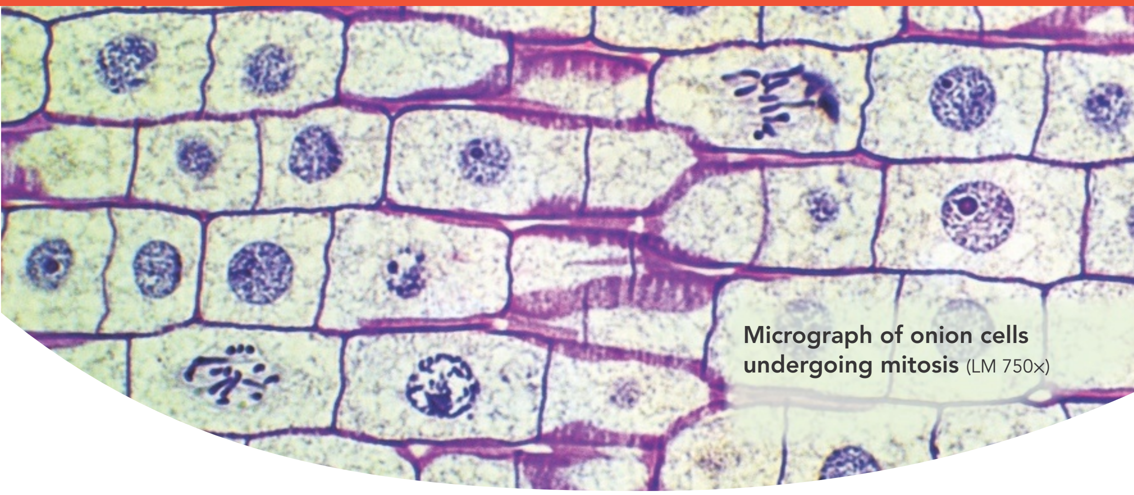
1. What factors limit the size of a cell?
2. What are the advantages and disadvantages of both asexual and sexual reproduction?

CRITICAL THINKING

3. **Calculate** The volume of a sphere increases with the cube of its radius. If the radius of a sphere increases from 2 cm to 6 cm, by what factor does its volume increase?
4. **Use Models** Compare a cell that has grown too large to be efficient with a wireless network that has too many users. Explain how both have the same two problems noted for the city shown in **Figure 11.3**. Illustrate how "division" helps in both cases.
5. **Synthesize Information** Aphids are a type of insect. They reproduce asexually in the spring and summer. They reproduce sexually in the fall. How might this pattern improve the species' chances of survival?

The Process of Cell Division

LESSON 11.2



Micrograph of onion cells undergoing mitosis (LM 750×)

KEY QUESTIONS

- *What is the role of chromosomes in cell division?*
- *What are the main events of the cell cycle?*
- *What happens during the phases of mitosis?*
- *How do daughter cells split apart after mitosis?*

HS-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

VOCABULARY

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

READING TOOL

In the cell cycle diagram in your **Biology Foundations Workbook,** each section represents the time the cell spends in each stage. Write the stages of the cell cycle into the diagram.

What role does cell division play in your life? You know that small children grow bigger every year. This growth depends on the production of new cells through cell division. But what happens when you are finished growing? Does cell division simply stop? Now, think about what must be happening when your body heals a cut or a broken bone. Where do the cells come from that heal a cut in your skin or seal together the fractured ends of a bone? Next, think about the daily wear and tear on your skin and on the cells of your digestive system. How about red blood cells that live for only about four months in your circulatory system? Where do the cells that replace them come from? The more you think about it, the more you will realize that cell division doesn't stop when we stop growing. In fact, cell division takes place all the time, keeping us healthy by replacing worn cells and regenerating the tissue we lose to injury or disease.

Chromosomes

What would happen if a cell were simply to split in two, without any advance preparation? The results might be disastrous, especially if some of the cell's essential genetic information wound up in one of the daughter cells but not in the other. In order to make sure this doesn't happen, cells first make a complete copy of their genetic information before cell division begins.

Even a small cell like the bacterium *E. coli* has a tremendous amount of genetic information in the form of DNA. In fact, the total length of this bacterium's DNA molecule is 1.6 mm, roughly 1000 times longer than the cell itself. In terms of scale, imagine a 300-meter rope stuffed into a school backpack. Cells can handle such large molecules only by careful packaging. Genetic information is bundled into packages of DNA known as **chromosomes**.

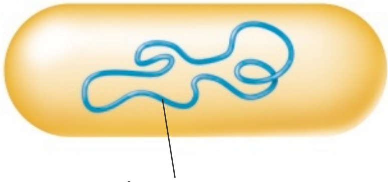


Figure 11-6
Prokaryotic Chromosome

In most prokaryotes, a single chromosome holds most of the organism's DNA.

Prokaryotic Chromosomes Prokaryotic cells lack membrane-bound nuclei and many of the organelles found in eukaryotes. The DNA molecules of prokaryotic cells are found in the cytoplasm, along with most of the other contents of the cell. Most prokaryotes contain a single circular DNA chromosome, as you can see in **Figure 11-6**. That circular DNA contains all, or nearly all, of the cell's genetic information.

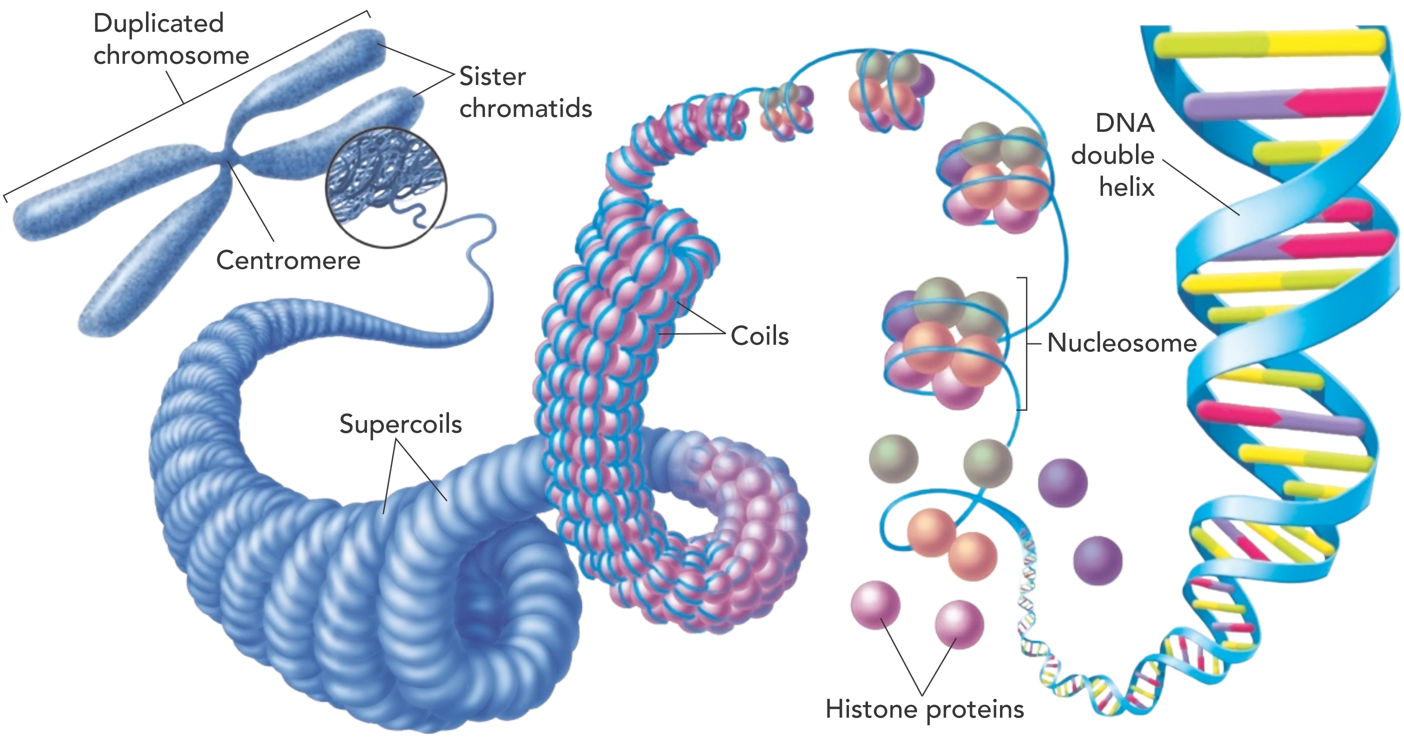
Eukaryotic Chromosomes Eukaryotic cells generally have much more DNA than prokaryotes have, and therefore they contain multiple chromosomes. Fruit flies, for example, have 8 chromosomes per cell, carrot cells have 18, and human cells have 46. The chromosomes in eukaryotic cells contain DNA tightly bound to proteins known as histones. This complex of DNA and protein is referred to as **chromatin**. DNA tightly coils around the histones, and together, the DNA and histone molecules form beadlike structures called nucleosomes. Nucleosomes pack together to form thick fibers, which condense even further during cell division. The X-like chromosome shape you often see drawn in textbooks is actually a duplicated chromosome with supercoiled chromatin, as shown in **Figure 11-7**.

Why do cells go to such lengths to package their DNA into chromosomes? One of the principal reasons is to ensure equal division of DNA when a cell divides. ***Chromosomes are precisely separated into two daughter cells during cell division.***

READING CHECK **Compare** How are the chromosomes in eukaryotic cells different from those in prokaryotic cells?

Figure 11-7
Eukaryotic Chromosome

As a eukaryotic cell prepares for division, each chromosome coils more and more tightly to form a compact structure.



The Cell Cycle

Cells go through a series of events known as the **cell cycle** as they grow and divide. ***During the cell cycle, a cell grows, prepares for division, and then divides to form two daughter cells.*** Each daughter cell then moves into a new cell cycle of activity, growth, and division.

READING TOOL

As you read, create a timeline of the sequence of events of the cell cycle. Include details for each event.

The Prokaryotic Cell Cycle

The prokaryotic cell cycle is a regular pattern of growth, DNA replication, and cell division that can take place very rapidly under ideal conditions. Researchers are just beginning to understand how the cycle works in prokaryotes, and relatively little is known about its details. It is known that most prokaryotic cells begin to replicate, or copy, their DNA chromosomes once they have grown to a certain size. When DNA replication is complete, or nearly complete, the cell begins to divide.

The process of cell division in prokaryotes is a form of asexual reproduction known as binary fission. Once the chromosome has been replicated, the two DNA molecules attach to different regions of the cell membrane. A network of fibers forms between them, stretching from one side of the cell to the other. These fibers constrict and the cell is pinched inward, dividing the cytoplasm and chromosomes between two newly formed cells. Binary fission results in the production of two genetically identical cells.

INTERACTIVITY

Learn about the various stages of the cell cycle.

The Eukaryotic Cell Cycle

In contrast to prokaryotes, much more is known about the eukaryotic cell cycle. As you can see in **Figure 11-8**, the eukaryotic cell cycle consists of four stages: G_1, S, G_2, and M. The length of each stage of the cell cycle—and the length of the entire cell cycle—varies depending on the type of cell.

At one time, biologists described the life of a cell as one cell division after another separated by an "in-between" period of growth called **interphase**. We now appreciate that a great deal happens in the time between cell divisions, so interphase is now divided into three phases: G_1, S, and G_2.

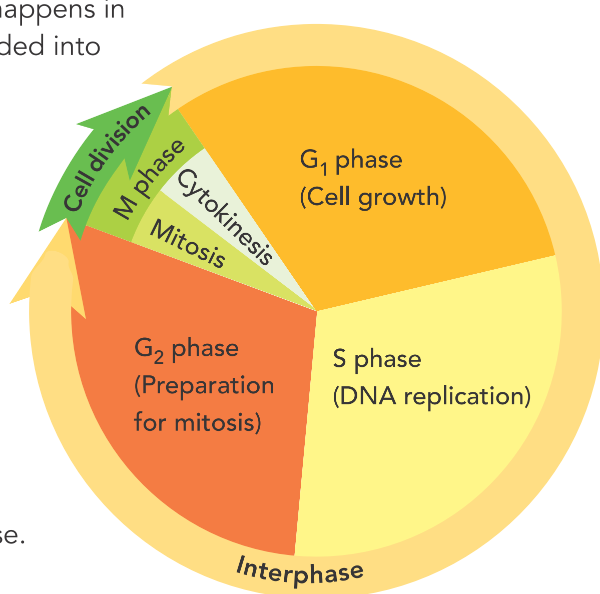
G_1: Cell Growth Cells do most of their growing during the G_1 phase. In this phase, cells increase in size and synthesize new proteins and organelles. The *G* in G_1 and G_2 stands for "gap," but the G_1 and G_2 phases are actually periods of intense growth and activity.

S: DNA Replication The G_1 phase is followed by the S phase. The *S* stands for "synthesis." During the S phase, new DNA is synthesized as the chromosomes are replicated. By the end of the S phase, the cell contains twice as much DNA as it did at the beginning of the phase.

Figure 11-8

The Cell Cycle

During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells. The cell cycle includes four phases—G_1, S, G_2, and M.



INTERACTIVITY

Observe how cells duplicate themselves through mitosis.

G_2: Preparing for Cell Division When DNA replication is completed, the cell enters the G_2 phase. G_2 is usually the shortest of the three phases. During the G_2 phase, many of the organelles and molecules required for cell division are produced. When the events of the G_2 phase are completed, the cell is ready to enter the M phase and begin the process of cell division.

M Phase: Cell Division The M phase of the cell cycle, which follows interphase, produces two daughter cells. The M phase takes its name from the process of mitosis. During the normal cell cycle, interphase can be quite long. In contrast, the process of cell division usually takes place quickly.

In eukaryotes, cell division occurs in two main stages. The first stage of the process, the division of the cell nucleus, is called **mitosis**. The second stage, the division of the cytoplasm, is called **cytokinesis**. In many cells, the two stages may overlap, so that cytokinesis begins while mitosis is still taking place.

BUILD VOCABULARY

Root Words The word root **kinesis** is a noun that means "movement" or "motion."

READING CHECK **Define** What events occur during interphase?

Mitosis

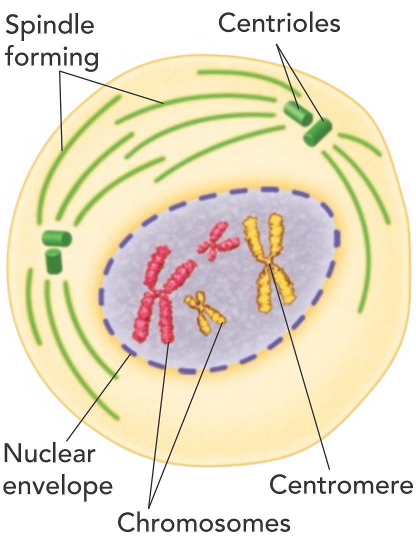
Biologists divide the events of mitosis into four phases: prophase, metaphase, anaphase, and telophase. Depending on the type of cell, mitosis may last anywhere from a few minutes to several days.

Prophase

The first phase of mitosis, **prophase**, is usually the longest and may take up to half of the total time required to complete mitosis. ***During prophase, the genetic material inside the nucleus condenses and the duplicated chromosomes become visible.*** Outside the nucleus, a spindle starts to form.

During prophase, each duplicated chromosome condenses to appear as two thick strands known as sister **chromatids** (KROH muh tids), attached at a point called the **centromere**. When the process of mitosis is complete, the sister chromatids will have separated, one to each of the daughter cells. Also during prophase, the cell starts to build a spindle, a fanlike system of microtubules that will help to separate the duplicated chromosomes. Spindle fibers extend from a region called the centrosome, where tiny paired structures called **centrioles** are located. Early in prophase, the centrioles move toward opposite ends, or poles, of the cell. Plant cells lack centrioles, and organize spindles directly from their centrosome regions.

Prophase



Quick Lab — Open-Ended Inquiry

Make a Model of Mitosis

1. With your partner, discuss a plan for modeling the stages of mitosis. Choose available materials, such as yarn, chenille stems, or candy pieces, to represent the chromosomes. Then describe how to use the materials to demonstrate each stage.
2. Carry out your plan. Make sketches or take photographs of each stage.
3. Organize the sketches or photos to show all the stages of mitosis in the proper order. Add labels or captions to create a flip book, slide show, or video presentation.

ANALYZE AND CONCLUDE

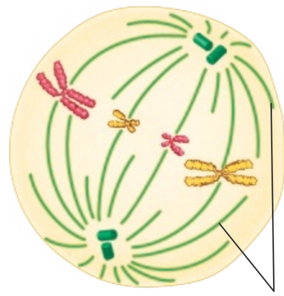
1. **Use Models** How many chromosomes did you include in your model?
2. **Evaluate Models** How accurately does your model show an original cell and the two daughter cells that are produced after mitosis? Compare your model with other representations of mitosis, such as those shown in the lesson. How could you improve your model?
3. **Use Models** Use your model to explain the function of mitosis to your classmates.

Metaphase The second phase of mitosis, **metaphase**, is generally the shortest. ***During metaphase, the centromeres of the duplicated chromosomes line up across the center of the cell.*** Spindle fibers connect the centromere of each chromosome to the two poles of the spindle. The cell is now ready to separate those sister chromatids.

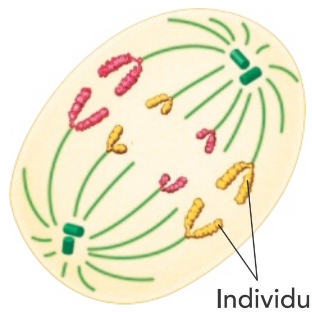
Anaphase The third phase of mitosis, **anaphase**, begins when sister chromatids suddenly separate and begin to move apart. Once anaphase begins, each sister chromatid is now considered an individual chromosome. ***During anaphase, the chromosomes separate and move along spindle fibers to opposite ends of the cell.*** Anaphase movement requires the rapid disassembly of microtubules as chromosomes move toward the poles of the mitotic spindle. Anaphase comes to an end when this movement stops and the chromosomes are completely separated into two groups. The microtubules that once made up the mitotic spindle have almost completely disassembled by the end of anaphase.

Telophase Following anaphase is **telophase**, the final phase of mitosis. ***During telophase, the chromosomes, which were distinct and condensed, begin to spread out into a tangle of chromatin.*** A nuclear envelope re-forms around each cluster of chromosomes, and gradually a nucleolus becomes visible in each daughter nucleus. Mitosis is complete, but the process of cell division has one more step.

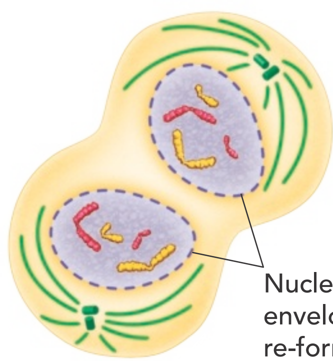
READING CHECK Review What structures are responsible for the movement of chromosomes to the center of the cell in metaphase and their separation in anaphase?



Metaphase



Anaphase



Telophase

Cytokinesis

As a result of mitosis, two nuclei—each with a duplicate set of chromosomes—are formed. All that remains to complete the M phase of the cycle is cytokinesis, the division of the cytoplasm to form two separate cells. Cytokinesis usually occurs at the same time as telophase. ***Cytokinesis completes the process of cell division by dividing one cell into two.*** The process of cytokinesis differs in animal and plant cells, as shown in **Figure 11-9**.

Cytokinesis in Animal Cells During cytokinesis in most animal cells, the cell membrane is drawn inward until the cytoplasm is pinched into two nearly equal parts. Each part contains its own nucleus and cytoplasmic organelles.

Cytokinesis in Plant Cells Cytokinesis in plant cells proceeds differently. The cell membrane is not flexible enough to draw inward because of the rigid cell wall that surrounds it. Instead, a structure known as the cell plate forms halfway between the divided nuclei. The cell plate gradually develops into cell membranes that separate the two daughter cells. A cell wall then forms in between the two new membranes, completing the process.

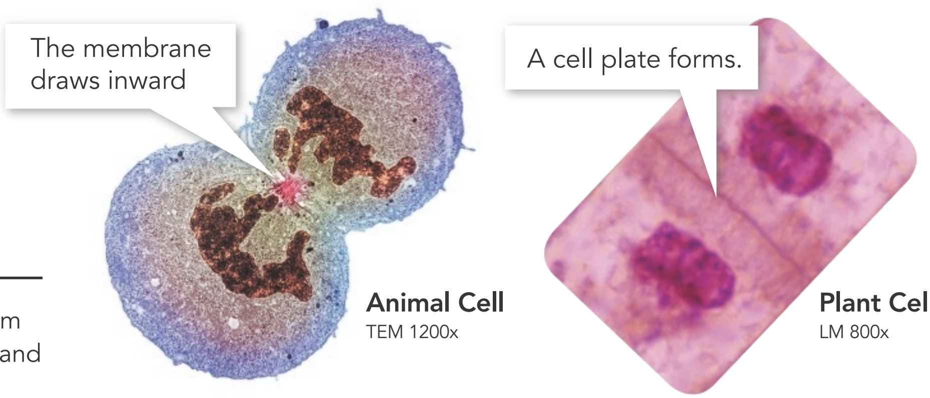


Figure 11-9
Cytokinesis

The division of the cytoplasm occurs differently in animal and plant cells.

HS-LS1-4

LESSON 11.2 Review

KEY QUESTIONS

1. What are chromosomes? How are they different between prokaryotes and eukaryotes?
2. What is the cell cycle?
3. What happens during each of the four phases of mitosis? Write one or two sentences for each phase.
4. What happens during cytokinesis?

CRITICAL THINKING

5. **Construct an Explanation** Explain how mitosis maintains the chromosome number of the original cells when forming new cells.
6. **Construct an Explanation** Describe the role of microtubules in mitosis. Why must microtubules both assemble and disassemble for mitosis to occur properly?

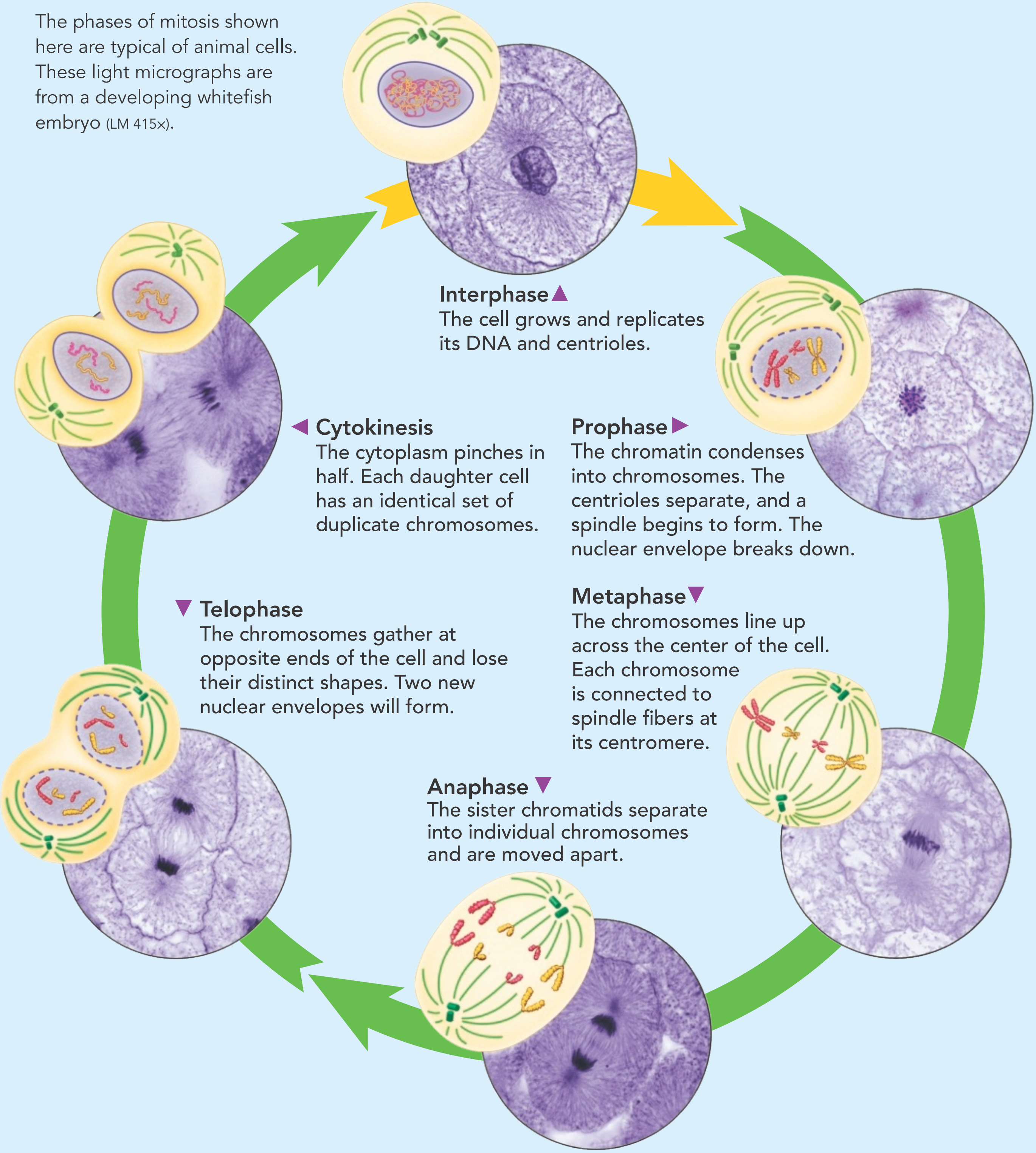
ANIMATION

Visual Summary

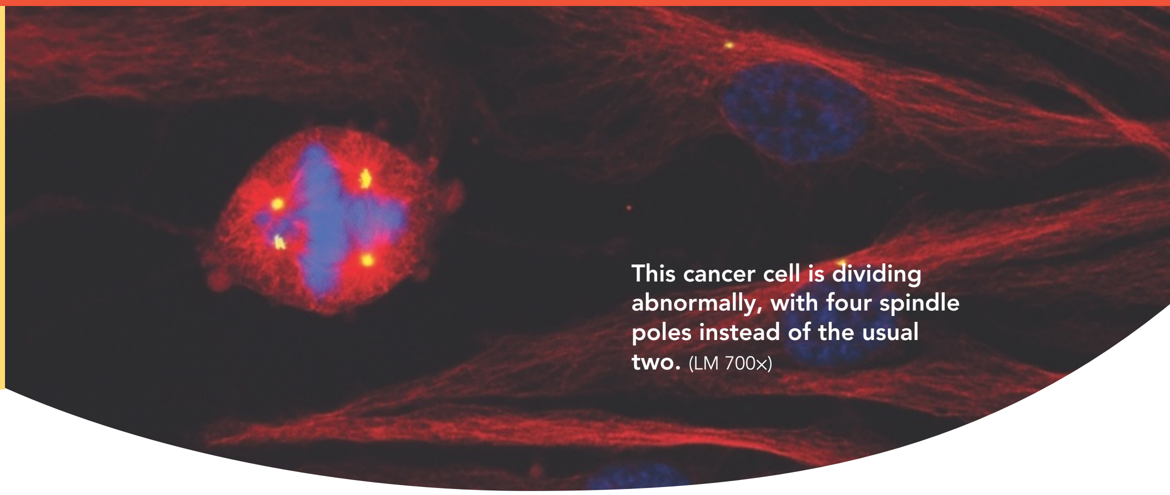
Figure 11-10

Mitosis

The phases of mitosis shown here are typical of animal cells. These light micrographs are from a developing whitefish embryo (LM 415×).



LESSON 11.3 Regulating the Cell Cycle



This cancer cell is dividing abnormally, with four spindle poles instead of the usual two. (LM 700x)

KEY QUESTIONS

- *How is the cell cycle regulated?*
- *How do cancer cells differ from other cells?*

VOCABULARY

growth factor
cyclin
apoptosis
cancer
tumor

READING TOOL

As you read, fill in the graphic organizer in your **Biology Foundations Workbook** with the key words from this lesson.

INTERACTIVITY

Explore how cell growth is regulated.

How do cells know when it is time to divide? One striking fact about cells in multicellular organisms is how carefully cell growth and cell division are controlled. Think of what might happen, for example, if the cells in one of your internal organs were to suddenly start growing while the other parts of the body did not. That's why careful control of the cell cycle is essential for orderly growth and development. If something goes wrong with that control, serious diseases such as cancer sometimes result. In the human body, for example, most muscle cells and nerve cells do not divide at all once they have developed. In contrast, blood-producing cells in the bone marrow, as well as cells of the skin and digestive tract, grow and divide regularly throughout life. In this way they produce new cells to replace those that wear out or break down.

Controls on Cell Division

When scientists grow cells in the laboratory, most cells will divide until they come into contact with one another. Once they do, they usually stop dividing and growing. What happens if those neighboring cells are suddenly scraped off the culture dish? The remaining cells will begin dividing again until they once again make contact with other cells. This simple experiment shows that controls on cell growth and division can be turned on and off.

Something similar happens inside the body. Look at **Figure 11-11**. 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. New cells form, starting the process of healing. When the healing process nears completion, the rate of cell division slows, controls on growth are restored, and normal activities return.

Regulatory Proteins

For many years, biologists searched for a signal that might regulate the cell cycle—something that would "tell" the cell when it was time to divide, duplicate its chromosomes, or enter another phase of the cell cycle. They found out that there is not just one signal, but many. Scientists have identified dozens of proteins that help to regulate the cell cycle. ***The cell cycle is controlled by regulatory proteins both inside and outside the cell.***

Internal Regulators One group of internal regulatory proteins responds to events inside the cell. These proteins act as checkpoints, allowing the cell cycle to proceed only when certain events have taken place. For example, one set of checkpoint proteins makes sure a cell does not enter mitosis until its chromosomes have replicated. Another checkpoint prevents a cell from entering anaphase until spindle fibers have attached to each of the chromosomes.

External Regulators Proteins that respond to events outside the cell are called external regulatory proteins. External regulatory proteins direct cells to speed up or slow down the cell cycle. One important group of external regulatory proteins is the group made up of growth factors. **Growth factors** stimulate the growth and division of cells. These proteins are especially important during embryonic development and wound healing. Other external regulatory proteins on the surface of neighboring cells often have the opposite effect. These regulatory proteins cause cells to slow down or stop their cell cycles. This prevents excessive cell growth and keeps body tissues from disrupting one another.

READING CHECK Summarize Why must multicellular organisms tightly control the cell cycle?

BUILD VOCABULARY

Academic Words The verb regulate means "to control or direct." Therefore, a substance that *regulates* the cell cycle tells the cell whether to divide and when.

Up Close

Figure 11-11

Cell Growth and Healing

When a person breaks a bone, cells at the edges of the injury are stimulated to divide rapidly. The new cells that form begin to heal the break. As the bone heals, the cells stop dividing and growing.

Cyclins Biologists had been searching for years for the signal that regulates the cell cycle because they realized that it could help them treat diseases. Learning that there is not just one signal but many has made that job more complicated.

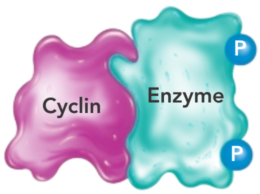
Scientists discovered the first regulatory protein in the early 1980s. When they injected this protein into a nondividing cell, a mitotic spindle would form. They named this protein **cyclin** because it seemed to regulate the cell cycle. Investigators have since discovered a family of proteins known as cyclins that regulate the timing of the cell cycle in eukaryotic cells. Cyclins rise and fall in a pattern, as shown in **Figure 11-12**.

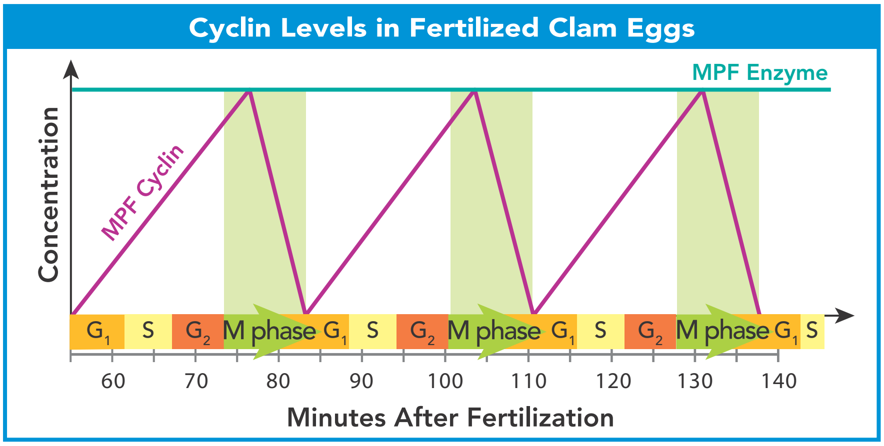
Figure 11-12

Cyclin Levels

Cyclin binds with an enzyme to produce mitosis-promoting factor (MPF). The levels of MPF Cyclin rise and fall to control the cell cycle.

Mitosis Factor





Apoptosis Just as new cells are produced every day in a multicellular organism, many other cells die. A cell may die by accident due to damage or injury, or a cell may actually be "programmed" to die. **Apoptosis** (ayp up TOH sis) is a process of programmed cell death. Once apoptosis is triggered, a cell undergoes a series of controlled steps leading to its self-destruction. First, the cell and its chromatin shrink, and then parts of the cell's membranes break off. Neighboring cells then quickly clean up the cell's remains.

Apoptosis plays a key role in growth and development by shaping the structure of tissues and organs. When apoptosis does not occur as it should in humans, a number of diseases can result. For example, the cell loss seen in AIDS and Parkinson's disease can result if too much apoptosis occurs.

READING TOOL

Review the timeline you created for Lesson 2, which showed the events of the cell cycle. Create a similar timeline for apoptosis.

Analyzing Data

The Rise and Fall of Cyclins

Scientists measured cyclin levels in clam embryonic cells as the cells went through their first mitotic divisions after fertilization. The data are shown in the graph in **Figure 11-12**.

Cyclins are continually produced and destroyed within cells. Cyclin production signals cells to enter mitosis, whereas cyclin destruction signals cells to stop dividing and to enter interphase.

ANALYZE AND CONCLUDE

1. **Analyze Graphs** How long does cyclin production last during a typical cell cycle in embryonic clam cells?
2. **Apply Scientific Reasoning** During which part of the cell cycle does cyclin production begin? How quickly is cyclin destroyed?
3. **Form a Hypothesis** Suppose that the regulators that control cyclin production are no longer produced. Hypothesize two possible outcomes.

Cancer: Uncontrolled Cell Growth

Why is cell growth regulated so carefully? The principal reason may be that the consequences of uncontrolled cell growth in a multicellular organism are very severe. **Cancer**, a disorder in which body cells lose the ability to control growth, is one such example.

Cancer cells do not respond to the signals that regulate the growth of most cells. As a result, the cell cycle is disrupted, and cells grow and divide uncontrollably. Cancer cells form a mass of cells called a **tumor**. However, not all tumors are cancerous. Some are benign, or noncancerous. A benign tumor does not spread to surrounding healthy tissue or to other parts of the body. Cancerous tumors, such as the one shown in **Figure 11-13**, are malignant. Malignant tumors invade and destroy surrounding healthy tissue.

As the cancer cells spread to surrounding healthy tissue, they absorb the nutrients needed by other cells, block nerve connections, and prevent the organs they invade from functioning properly. Soon, the delicate balances that exist in the body are disrupted, and life-threatening illness results.

What Causes Cancer? Cancers are caused by defects in the genes that regulate cell growth and division. There are several sources of such defects, including smoking or chewing tobacco, radiation exposure, and even viral infection. All cancers, however, have one thing in common: The control over the cell cycle has broken down. Some cancer cells will no longer respond to external growth regulators, while others fail to produce the internal regulators that ensure orderly growth.

An astonishing number of cancer cells have a defect in a gene for a checkpoint protein known as p53, which normally halts the cell cycle until all chromosomes have been properly replicated. Damaged or defective p53 genes cause cells to lose the information needed to respond to signals that normally control their growth.

READING CHECK **Make Generalizations** Why is the presence of cancer cells so harmful to the body?

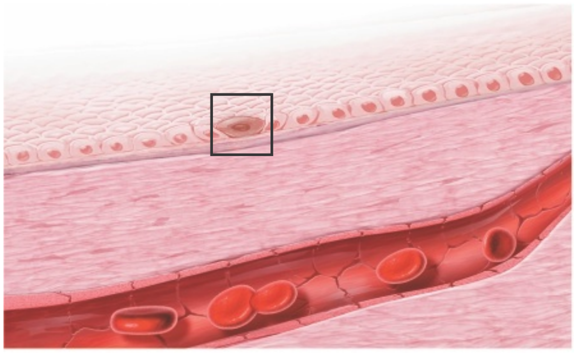
ANIMATION

hhmi | BioInteractive

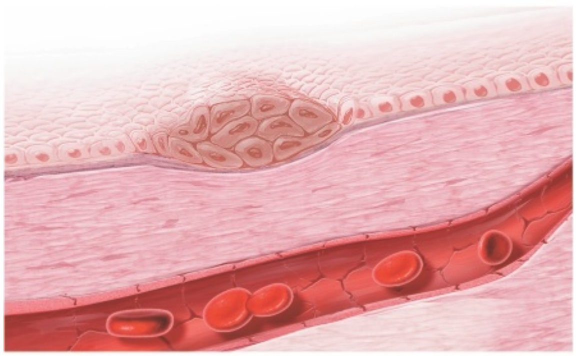
Figure 11-13

Growth of Cancer Cells

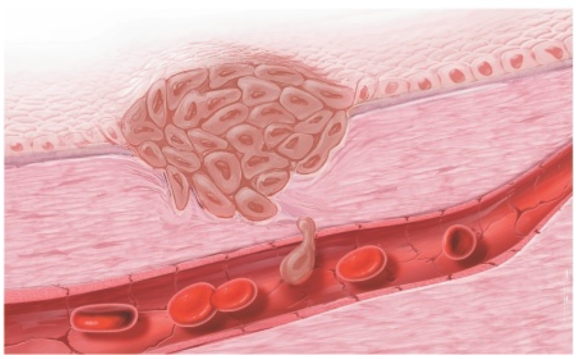
Normal cells grow and divide in a carefully controlled fashion. Cells that are cancerous lose this control and continue to grow and divide, producing tumors.



1 A cell begins to divide abnormally.



2 The cancer cells produce a tumor, which begins to displace normal cells and tissues.



3 Cancer cells are particularly dangerous because of their tendency to spread once they enter the bloodstream or lymph vessels. The cancer then moves into other parts of the body and forms secondary tumors, a process called metastasis.

INTERACTIVITY

Investigate how the cell cycle is regulated and what happens when things go wrong.

Treatments for Cancer

When a cancerous tumor is localized, it can often be removed by surgery. Skin cancer, one of the most common forms of the disease, can usually be treated this way. Melanomas, the most serious form of skin cancer, can be removed surgically, but only if spotted very early.

As shown in **Figure 11-14**, cancerous tumors tend to grow more rapidly than normal cells. For this reason, they need to copy their DNA relatively quickly. This makes them especially vulnerable to damage from high-energy radiation. As a result, many tumors can be effectively treated with carefully targeted beams of radiation.

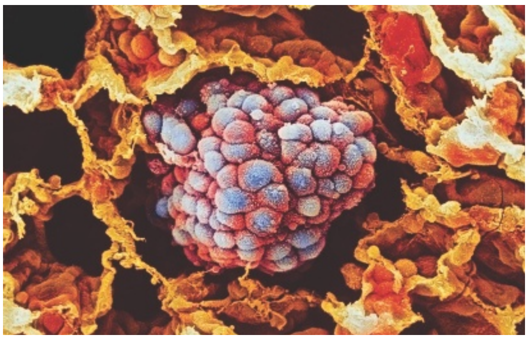
Medical researchers have worked for years to develop chemical compounds that would kill cancer cells, or at least slow their growth. The use of such compounds against cancer is known as chemotherapy. Great advances in chemotherapy have taken place in recent years and have even made it possible to cure some forms of cancer. However, because most chemotherapy compounds target rapidly dividing cells, they also interfere with cell division in normal, healthy cells. This produces serious side effects in many patients, which is why researchers are trying to find highly specific ways in which cancer cells can be targeted for destruction while leaving healthy cells unaffected.

Cancer is a serious disease. Understanding and combating cancer remains a major scientific challenge, but scientists at least know where to start. Cancer is a disease of the cell cycle, and conquering cancer will require an even deeper understanding of the processes that control cell division.

Figure 11-14

Cancer Research

Thanks to the work of researchers around the world, cancer can be treated more effectively than it was in the past. The false-colored micrograph shows a small cancerous tumor (blue) in the air sacs of the lungs.



(SEM: 240×)

LESSON 11.3 Review

KEY QUESTIONS

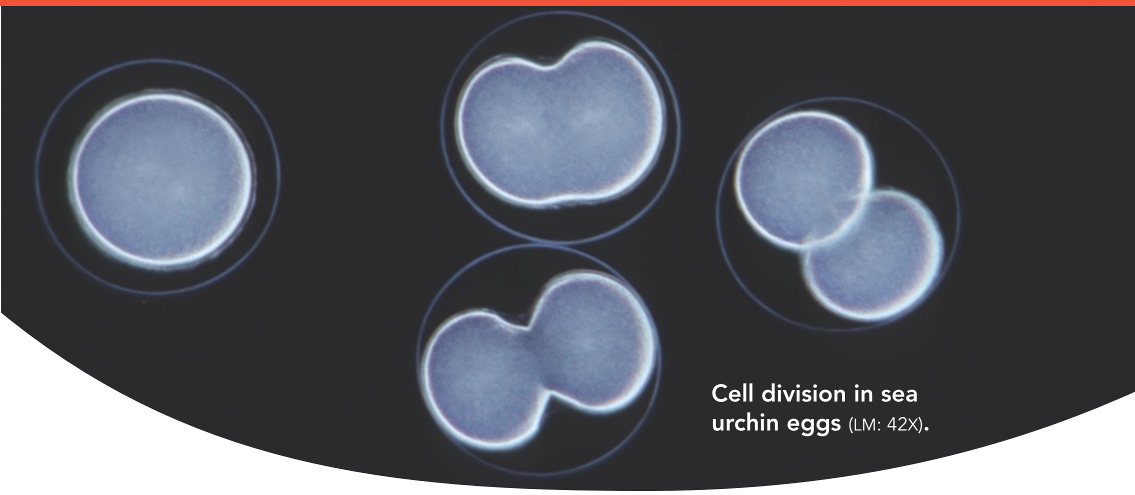
1. Name the two types of proteins that regulate the cell cycle. How do these proteins work?
2. Why is cancer considered a disease of the cell cycle?

CRITICAL THINKING

3. **Translate Scientific Information** How did experimental results show the effect of cyclins on the cell cycle?
4. **Construct an Explanation** How might a drug that alters events in mitosis or the cell cycle be useful for treating cancer?

Cell Differentiation

LESSON 11.4



Cell division in sea urchin eggs (LM: 42X).

KEY QUESTIONS

- *How do cells become specialized for different functions?*
- *What are stem cells?*
- *What are some possible benefits and issues associated with stem cell research?*

HS-LS1-4: Use a model to illustrate the role of cellular division (mitosis) and differentiation in producing and maintaining complex organisms.

VOCABULARY
embryo
differentiation
totipotent
blastocyst
pluripotent
stem cell
multipotent

READING TOOL

In the chart in your **Biology Foundations Workbook,** fill in the details that support the main ideas from this lesson.

VIDEO

Learn how meat can be grown in a lab using stem cells.

Each of us started life as just one cell. So, for that matter, did your pet dog, a sea urchin, and the petunia on a windowsill. Cell division explains how one cell could produce millions or even billions of cells in each of these organisms, but it leaves one critical question unanswered: Why do some cells turn into muscle cells, some into nerve cells, and others into bone and skin cells? Plainly stated, how do cells become so different from one another?

From One Cell to Many

Animals and higher plants pass through a developmental stage called an **embryo**, from which the adult organism is gradually produced. During the developmental process, cells become more and more different from one another and specialized for particular functions. **Figure 11-15** shows some of the specialized cells found in the parts of a plant.

Figure 11-15

Specialized Plant Cells

The first cell of a plant forms inside a reproductive structure, such as a flower. After many cell divisions, the new plant develops the specialized tissues it needs to survive as a multicellular organism.

Leaf tissue (LM: 255X) — Root tissues (LM: 46X) — Cross-section of a stem (LM: 27X)

Defining Differentiation The process by which cells become specialized is known as **differentiation** (dif ur en shee AY shun). ***During the development of an organism, cells differentiate into many distinct cell types.*** A differentiated cell has become, quite literally, different from the embryonic cell that produced it and specialized to perform certain tasks, such as contraction, photosynthesis, or protection. Our bodies, and the bodies of all multicellular organisms, contain highly differentiated cells that carry out the jobs we need to perform to stay alive.

Mapping Differentiation The process of differentiation determines a cell's ultimate identity, such as whether it will spend its life as a nerve cell or a muscle cell. In some organisms, a cell's role is rigidly determined at a specific point in the course of development. In the microscopic worm *Caenorhabditis elegans*, for example, biologists have mapped the outcome of each and every cell division from fertilized egg to adult.

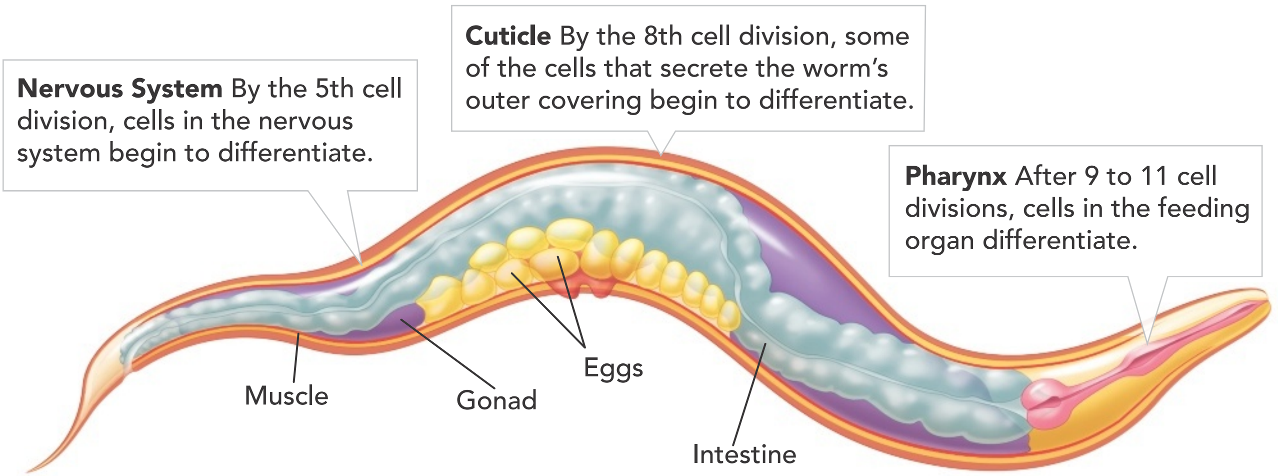
The process of cell differentiation in *C. elegans* begins with the very first division and continues throughout embryonic development. **Figure 11-16** shows when some of the cells found in the adult begin to differentiate during development. Every time a new worm develops, the process is the same, resulting in exactly 959 cells with precisely determined functions.

INTERACTIVITY

Figure 11-16

Differentiation in *C. elegans*

A fertilized egg develops into an adult worm after many cell divisions. Daughter cells from each cell division follow a specific path toward a role as a particular kind of cell.



Differentiation in Mammals Other organisms, including mammals, go through a more flexible process in which cell differentiation is controlled by a number of interacting factors in the embryo, many of which are still not well understood. What is known, however, is that adult cells generally do reach a point at which their differentiation is complete—when they can no longer turn into other types of cells.

READING CHECK **Identify** How does a single fertilized egg cell develop into so many different types of specialized cells?

Stem Cells and Development

One of the most important questions in biology is how all of the specialized, differentiated cell types in the body are formed from just a single cell, the fertilized egg, called a zygote. Biologists say that the zygote is **totipotent** (toh TIP uh tunt)—literally, able to do everything, to develop into any type of cell in the body (including the cells that make up the extra-embryonic membranes and placenta). Only the fertilized egg and the cells produced by the first few cell divisions of embryonic development are truly totipotent. If there is a "secret" by which cells start the process of differentiation, these are the cells that know that secret.

BUILD VOCABULARY

Prefixes The prefix *toti-* in **totipotent** means "entirely." The prefix *pluri-* in **pluripotent** means "several." Totipotent cells can develop into any type of cell, whereas pluripotent cells can develop into many different types of cells.

Human Development

After about four days of development, a human embryo forms into a **blastocyst**, a hollow ball of cells with a cluster of cells inside known as the inner cell mass. Even at this early stage, the cells of the blastocyst have begun to specialize. The outer cells form tissues that will attach the embryo to its mother, while the inner cell mass becomes the embryo itself. The cells of the inner cell mass are said to be pluripotent (plu ri POH tunt). **Pluripotent** cells can develop into any of the body's cell types, although they generally cannot form the tissues surrounding the embryo.

INTERACTIVITY

Explore stem cells and differentiated cells.

Stem Cells

As the name implies, **stem cells** sit at the base of a branching "stem" of development from which different cell types form. ***Stem cells are the unspecialized cells from which differentiated cells develop.*** Stem cells are found in the early embryo, of course, but they are also found in many places in the adult body.

Adult Stem Cells Cells in some tissues, like blood and skin, have a limited life span and must be constantly replaced. Pools of adult stem cells, found in various locations throughout the body, produce the new cells needed for these tissues. New blood cells differentiate from stem cells found in the bone marrow, and many skin stem cells are found in hair follicles. Small clusters of adult stem cells are even found in the brain, in the heart, and in skeletal muscle. These adult cells are referred to as **multipotent** (muhl TIP uh tunt) stem cells, because the types of differentiated cells they can form are usually limited to replacing cells in the tissues where they are found.

Exploration Lab Open-ended Inquiry

Regeneration in Planaria

Problem Are planarian cells multipotent or totipotent?

In this lab, you will design an experiment to determine whether planarian stem cells are multipotent or totipotent. Then you will share your results with the rest of the class. From these combined results, you will infer where multipotent or totipotent stem cells are found in a planarian's body.

You can find this lab in your digital course.

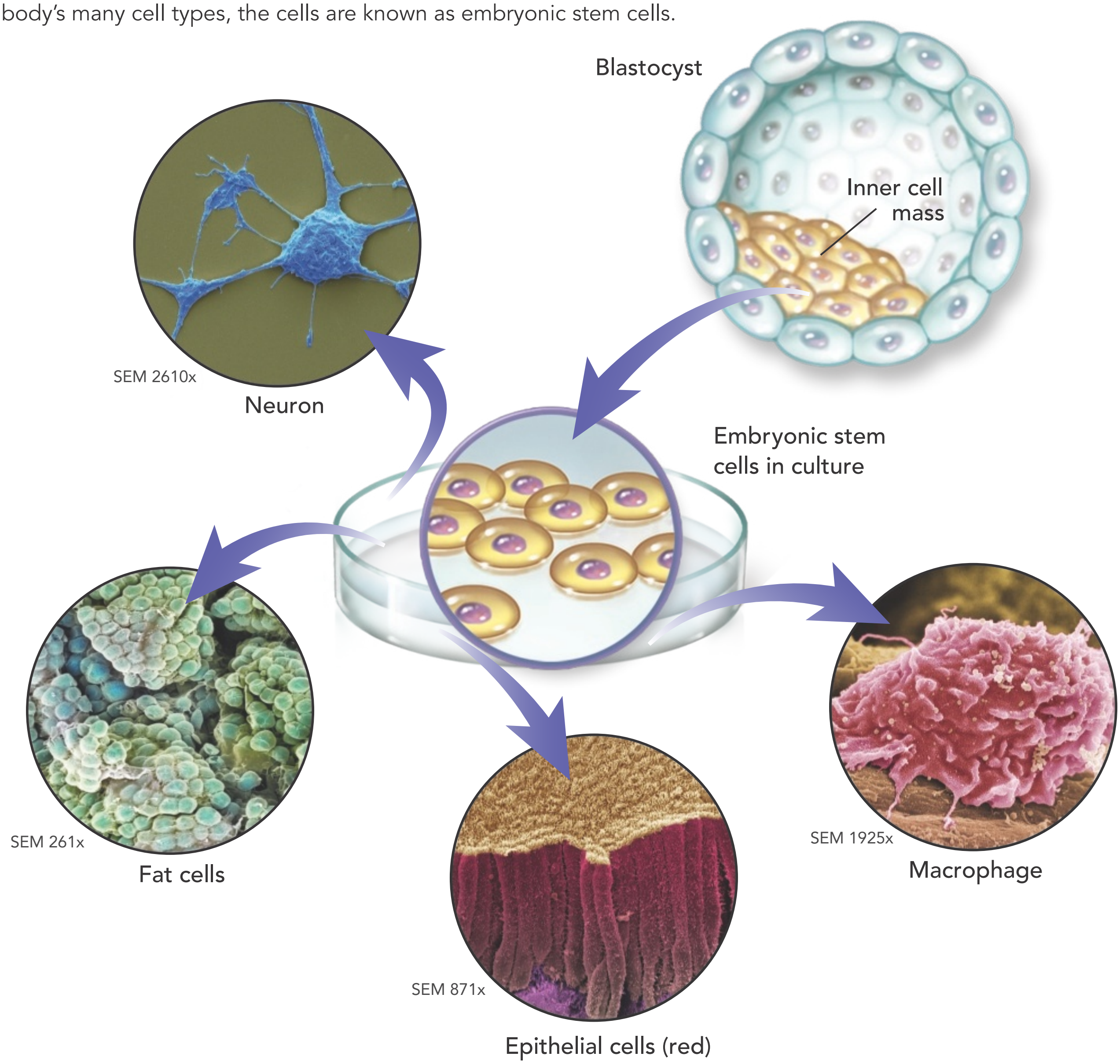
Embryonic Stem Cells Pluripotent embryonic stem cells are more versatile than adult stem cells, since they are capable of producing every cell type in the body, as shown in **Figure 11-17**. In laboratory experiments, scientists have managed to coax embryonic stem cells to differentiate into nerve cells, muscle cells, and even sperm and egg cells. In 1998, researchers at the University of Wisconsin found a way to grow human embryonic stem cells in culture, making it possible to explore the potential of these remarkable cells.

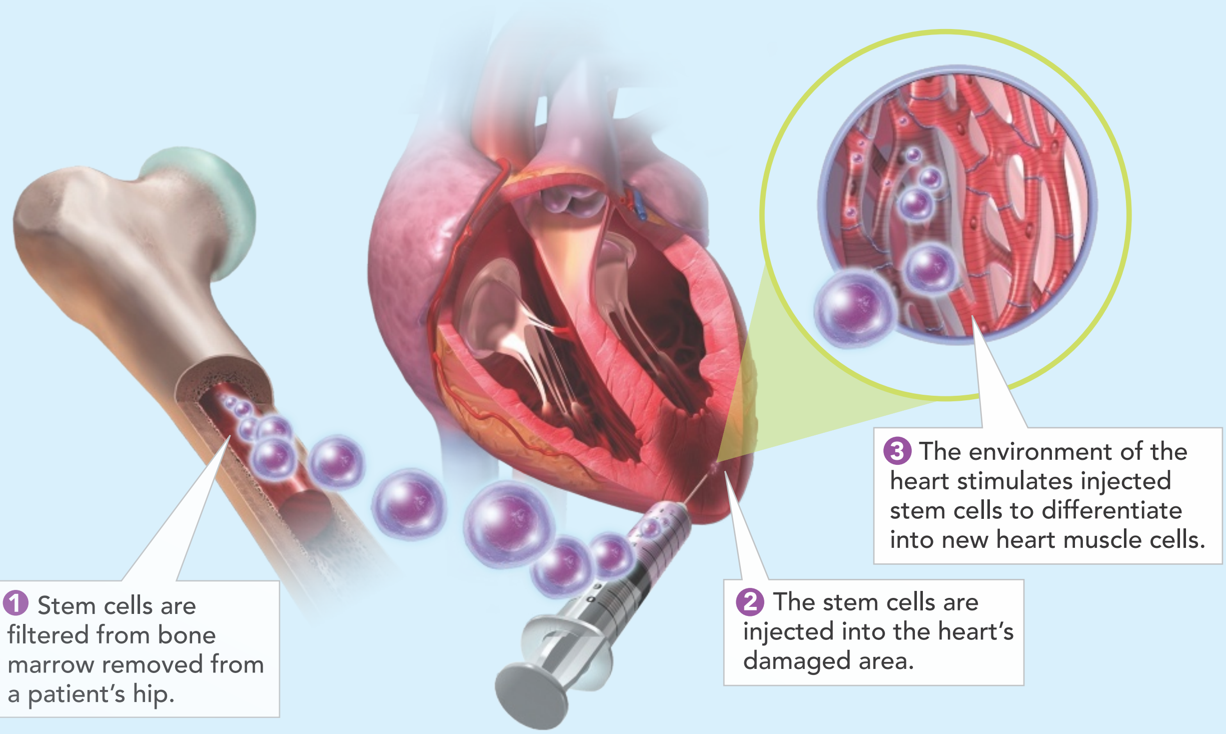
READING CHECK **Compare and Contrast** How are pluripotent and multipotent cells similar? How are they different?

Figure 11-17

Embryonic Stem Cells

After fertilization, the human embryo develops into a hollow ball of cells known as a blastocyst. The actual body of the embryo develops from the inner cell mass, a cluster of cells inside the blastocyst. Because of their ability to differentiate into each of the body's many cell types, the cells are known as embryonic stem cells.





Frontiers in Stem Cell Research

Basic research on stem cells takes on a special urgency in light of the importance it might have for human health. Heart attacks destroy cells in the heart muscle, strokes injure brain cells, and spinal cord injuries cause paralysis by breaking connections between nerve cells. Not surprisingly, the prospect of using stem cells to repair such cellular damage has excited medical researchers.

Figure 11-18 shows how stem cells might be used in the future to repair the damage caused by a heart attack. During a heart attack, the blood supply to part of the heart muscle is cut off, causing the cells to die. This damages the heart and prevents it from functioning properly. Stem cells harvested from the bone marrow might be cultured and then injected into the damaged portion of the heart. Once in place, the stem cells would "learn" what kind of cells they needed to be from the surviving cells around them. The stem cells would differentiate to become heart muscle cells.

Ethical Issues Because adult stem cells can be harvested from a willing donor, research with these cells has raised few ethical questions. This is not the case with embryonic stem cells, which are generally obtained in ways that cause the destruction of an embryo. For this reason, individuals who seek to protect human embryonic life oppose such research as unethical. Other groups support such research as essential for saving human lives and argue that it would be unethical to restrict research. ***Human embryonic stem cell research is controversial because the arguments for it and against it both involve ethical issues of life and death.*** However, new developments in research may help to address these concerns.

CASE STUDY

Figure 11-18

Future Treatment for Heart Disease?

Stem cell research may lead to new ways to reverse the damage caused by a severe heart attack. The diagram shows one method currently being investigated.

READING TOOL

Make a two-column chart to list the benefits and issues related to stem cell research. Fill in the chart as you read.

Induced Pluripotent Stem Cells A fundamental breakthrough took place in 2007 when Shinya Yamanaka of Kyoto University in Japan was able to convert human fibroblasts into cells that closely resembled embryonic stem cells. His work is summarized in **Figure 11-19**. These induced pluripotent stem cells (iPS cells), as they are known, are now widely used in research. Under certain conditions, iPS cells may be able to replace embryonic stem cells.

In a sense, what Yamanaka and his lab achieved was to take the work of John Gurdon in cloning frogs to its logical conclusion. Gurdon had shown that the nucleus of an adult cell could be reprogrammed to develop into an embryo by unknown factors in the cytoplasm of an egg cell. To produce iPS cells, Yamanaka found a set of precise conditions that could reprogram an entire cell to put it back into an embryonic state. For these two discoveries, more than 50 years apart, Gurdon and Yamanaka shared the Nobel Prize in Physiology or Medicine in 2012. Today, it seems clear that this work has the potential to solve the ethical problems that can make embryonic stem cell research highly controversial.

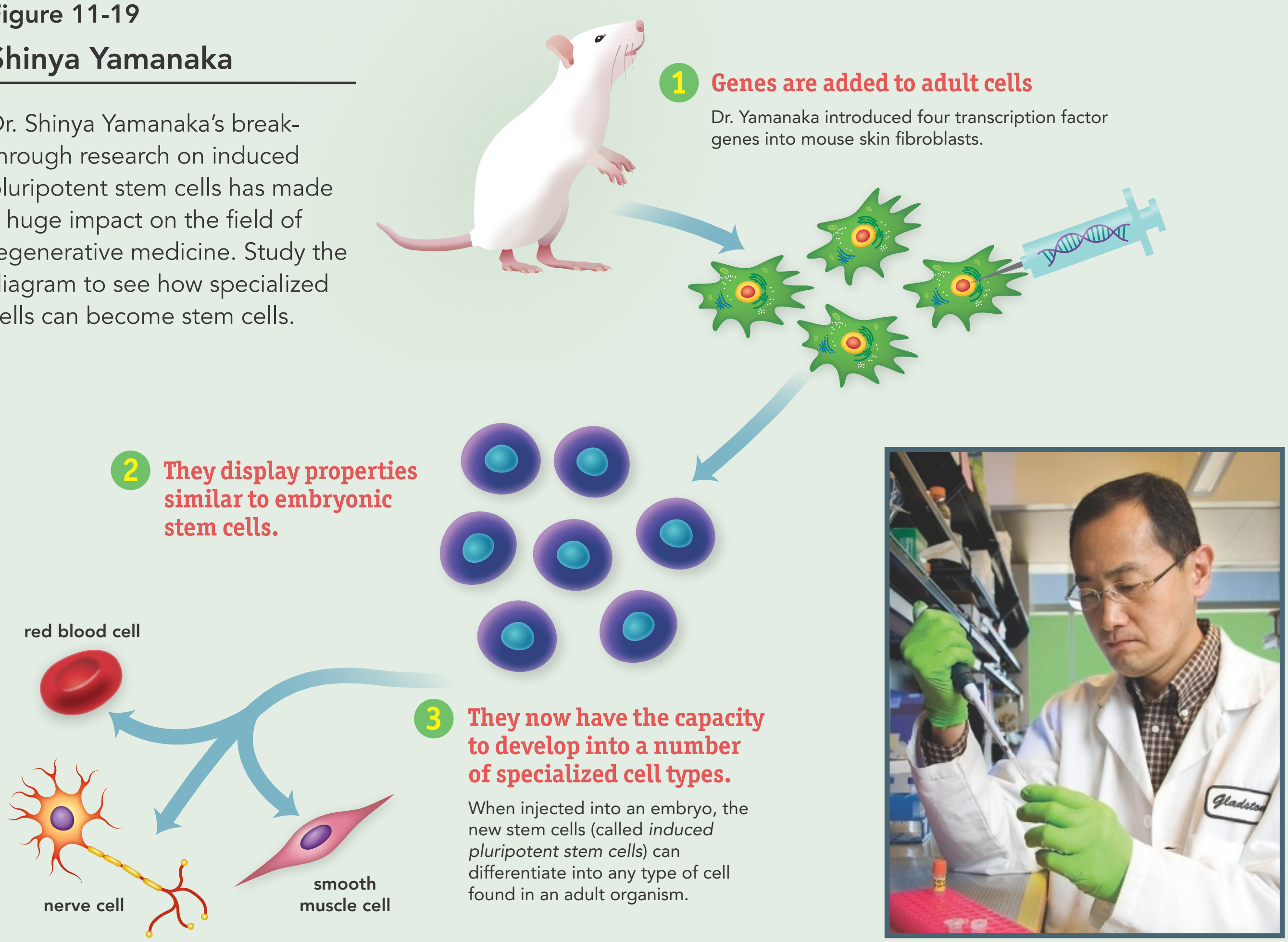
CASE STUDY

Figure 11-19

Shinya Yamanaka

Dr. Shinya Yamanaka's breakthrough research on induced pluripotent stem cells has made a huge impact on the field of regenerative medicine. Study the diagram to see how specialized cells can become stem cells.

Induced Pluripotent Stem Cells



Regenerative Medicine Work on many types of stem cells, including adult stem cells and iPS cells, has now opened up an entirely new field of medicine. Regenerative medicine makes use of stem cells to repair or replace damaged cells and tissues. By studying what happens when stem cells differentiate, researchers have now developed laboratory "recipes" that can remake cells into certain other cell types. These differentiated cells may then be used to repair or replace damaged or diseased cells, tissues, and even whole organs.

One promising treatment, now in clinical trials, uses stem cells to treat a form of macular degeneration. This condition affects the most sensitive part of the retina, the light-sensing layer of cells within the eye. When these cells break down, the result is a loss of vision. Experimental treatments have taken cells from a patient's own body and converted them into iPS cells. These cells were then stimulated to differentiate into cells that could be transplanted directly into the eye. In at least a few cases, this treatment seems to have reversed the process of macular degeneration.

Such research is not without risk, of course, since the transplanted cells may behave in unpredictable ways. They could differentiate into unwanted cell types, spread beyond the site of the transplant, or even grow uncontrollably into a tumor. This means that there are good reasons to proceed cautiously before putting these techniques into wide use. However, given its potential to alleviate human pain and suffering, it seems that the age of regenerative medicine is now upon us.

As researchers also know, some organisms do an excellent job of regenerating lost body parts. For example, if a sea star loses one or more of its arms, the central part of its body is capable of growing back the lost parts. Scientists continue to study the steps of this process. The research may lead to a method of replicating the steps in the human body.

VIDEO

Discover how animals regenerate lost body parts.

HS-LS1-4

LESSON 11.4 Review

KEY QUESTIONS

1. What happens during differentiation?
2. What are stem cells? How are embryonic stem cells different from adult stem cells?
3. What do the arguments for and against the use of stem cells in medical research share?

CRITICAL THINKING

4. **Construct an Explanation** Why is cell differentiation essential for every complex multicellular organism?
5. **Communicate Information** Use what you learned in this lesson to discuss how cells become specialized for different functions. Include an explanation of how the potential for specialization varies with cell type and how it varies over the life span of an organism.

CASE STUDY WRAP-UP

Will stem cells change the future of healing?

Scientists are able to reprogram certain differentiated cells to make them act like stem cells. However, stem cell technology involves both benefits and risks.

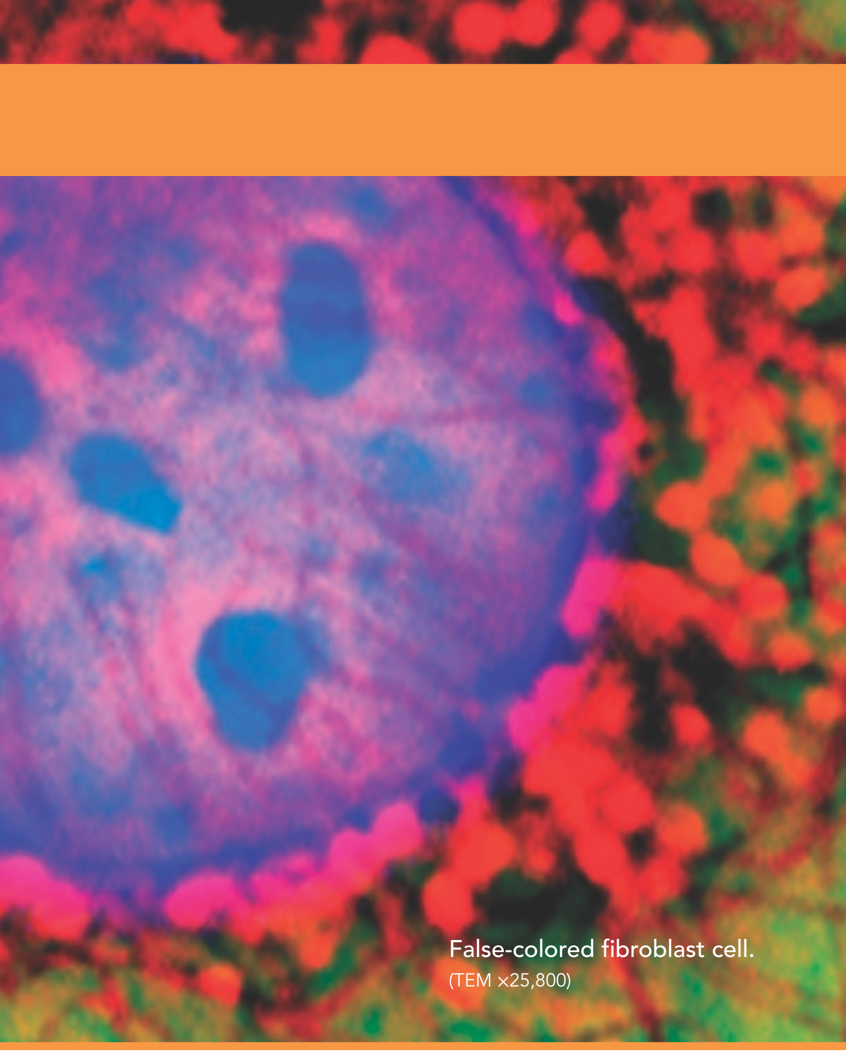
HS-ETS1-1

Make Your Case

Different people may analyze new technologies in different ways. Even when observers understand the technology and agree on the evidence, they may draw different conclusions about whether the benefits outweigh the drawbacks. As you research stem cell therapies, you will likely find conflicting opinions and judgments about them. Be sure to evaluate the reliability of your sources as you form your opinion.

Construct an Argument

1. **Conduct Research** Research stem cell technology. Find out about both sides of the issue, including scientific and ethical considerations. The United States Food and Drug Administration (FDA) is one useful source.
2. **Engage in Argument From Evidence** Based on your research, pick one side of the debate. Construct a useful set of guidelines for regulating stem cell therapies. Your guidelines should account for constraints such as costs, reliability, and safety, as well as social impacts.



False-colored fibroblast cell.
(TEM ×25,800)

Technology on the Case

Here Come the Clones

A clone is an exact genetic duplicate of a cell or an organism. John Gurdon created the first cloned frog when he transferred a nucleus from an adult frog cell into an egg cell. The result was a new frog, or clone, that had the same genes as the adult.

Cloning technology has advanced greatly since Gurdon's original experiments. In the 1990s, researchers in Scotland welcomed Dolly the sheep, the first cloned mammal. Today, more than 20 different kinds of animals have been cloned, including cattle, horses, and pigs. The technique is generally the same as Gurdon pioneered: An adult cell nucleus is transferred into the cytoplasm of an egg cell.

Cloning provides many benefits. Ranchers are expanding their herds by cloning their strongest, healthiest animals. Then the clones can be used as breeding stock. Government agencies, including the Federal Drug Administration (FDA), have confirmed the safety of milk and meat products from animal clones and their offspring.

Could cloning be used for human reproduction? It might be possible, but the practice raises many serious ethical issues. Many countries now prohibit human cloning. In other countries, including the United States, bans have been proposed but not yet enacted.

Careers on the Case

Work Toward a Solution

Researching and writing about stem cells and other scientific findings includes the coordination of many different types of careers.

Science Journalist

Science journalists are required to have a knowledge of science as well as communication skills. Newspapers, television networks, and online media all employ journalists to report on developments in science, technology, and engineering.

VIDEO

Watch this video to learn about other careers in biology.

CHAPTER 11
STUDY GUIDE

Go to your Biology Foundations Workbook for longer versions of these lesson summaries.

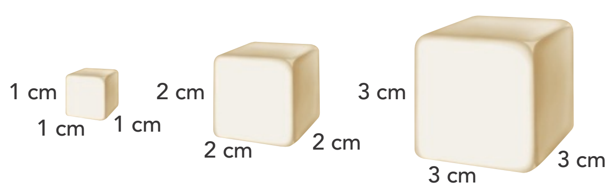
11.1 Cell Growth, Division, and Reproduction

The larger a cell becomes, the more demands the cell places on its DNA. In addition, a larger cell is less efficient in moving nutrients and waste materials across the cell membrane. The process of cell division solves this problem.

Asexual reproduction is the production of genetically identical offspring from a single parent. Offspring produced by sexual reproduction inherit some of their genetic information from each parent. Sexual reproduction produces genetic diversity and may help a species to survive in a changing environment.

- cell division
- asexual reproduction
- sexual reproduction

Ratio of Surface Area to Volume in Cells



Cause and Effect What changes occur to the ratio of surface area to volume as a cell grows?

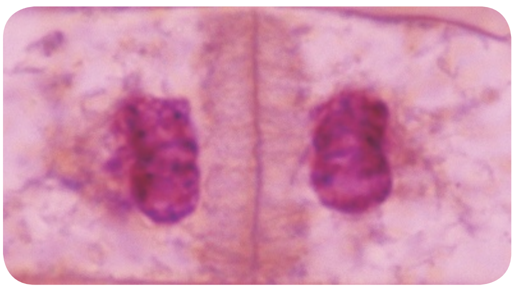
11.2 The Process of Cell Division

Genetic information is bundled into packages of DNA known as chromosomes. Prokaryotic cells have a single circular chromosome. Eukaryotic cells have multiple chromosomes enclosed in the nucleus.

Cell division in prokaryotes is a form of asexual reproduction known as binary fission. The eukaryotic cell cycle consists of four stages: cell growth, DNA replication, preparing for cell division, and cell division.

Mitosis is the division of the cell nucleus. During mitosis, chromosomes duplicate and condense into sister chromatids, which line up and then separate. In the final phase of mitosis, the separated chromosomes cluster and form duplicate nuclei. After mitosis, cytoplasm divides in the process known as cytokinesis, forming two daughter cells.

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



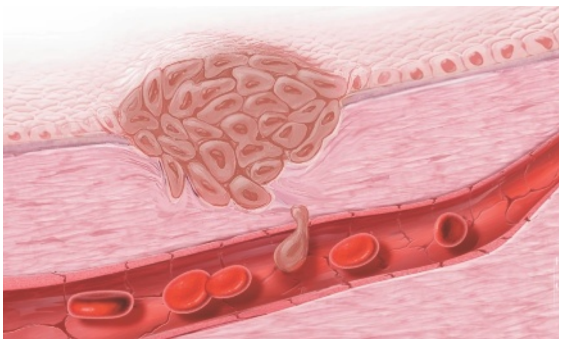
Classify What type of cell is undergoing cytokinesis in the photo? How do you know?

11.3 Regulating the Cell Cycle

Cell cycles are regulated by internal proteins such as cyclin and external proteins such as growth factors. Other external regulatory proteins cause cells to slow down or stop their cell cycles. Apoptosis is a process of programmed cell death, which shapes the structure of tissues and organs.

Cancer results in uncontrolled cell growth and division. Cancer cells form tumors, which invade and destroy surrounding healthy tissue. Rapidly growing cancer cells can be targeted by radiation or chemotherapy or by surgically removing the tumor.

- growth factor
- cyclin
- apoptosis
- cancer
- tumor



Interpret Diagrams Write a caption to describe the events shown in the illustration.

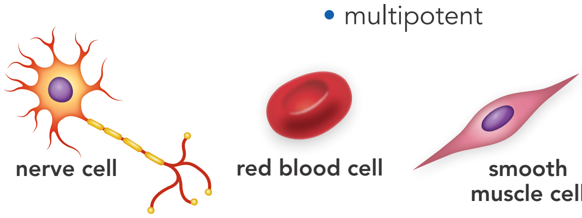
11.4 Cell Differentiation

Differentiation is the process by which cells become specialized. The differentiation process can be mapped in simple organisms but the process is more complicated in more complex organisms.

A zygote, the fertilized egg, is totipotent, in that it will develop into any type of cell for the organism, including cells that make up the extra-embryonic membranes and placenta. Embryonic stem cells are pluripotent, which means they are able to produce every type of cell. Adult stem cells are multipotent, so they are capable of replacing cells in the tissues where they are found.

The use of embryonic stem cells for research raises many ethical concerns, but stem cell research has made promising advances in repairing or replacing damaged cells and tissues.

- embryo
- differentiation
- totipotent
- blastocyst
- pluripotent
- stem cell
- multipotent



Compare How is a differentiated cell different from a stem cell?

Organize Information

Describe the events that occur in each stage of mitosis and cytokinesis.

Prophase	Metaphase	Anaphase	Telophase	Cytokinesis
1.	2.	3.	4.	5.

PERFORMANCE-BASED ASSESSMENT

Taxol
A Drug, a Poison, or Both?

Construct an Explanation

HS-LS1-4, HS-ETS1-1, CCSS.ELA-LITERACY.RST.9-10.7, CCSS.ELA-LITERACY.RST.9-10.10

STEM As you read in this chapter, cell division is an essential process in the life of a multicellular organism. Repeated rounds of cell division allowed you to develop from a single cell into the fully functioning, inquisitive science student that you are today! Proper cell division is also essential to allow your body to recover from injury, and to replace damaged or diseased cells.

Generally, cell division is a tightly controlled and regulated process. But sometimes something goes wrong and that control is lost. The result may be cancer, a disease in which rapidly dividing cells form clusters known as tumors and invade tissues throughout the body.

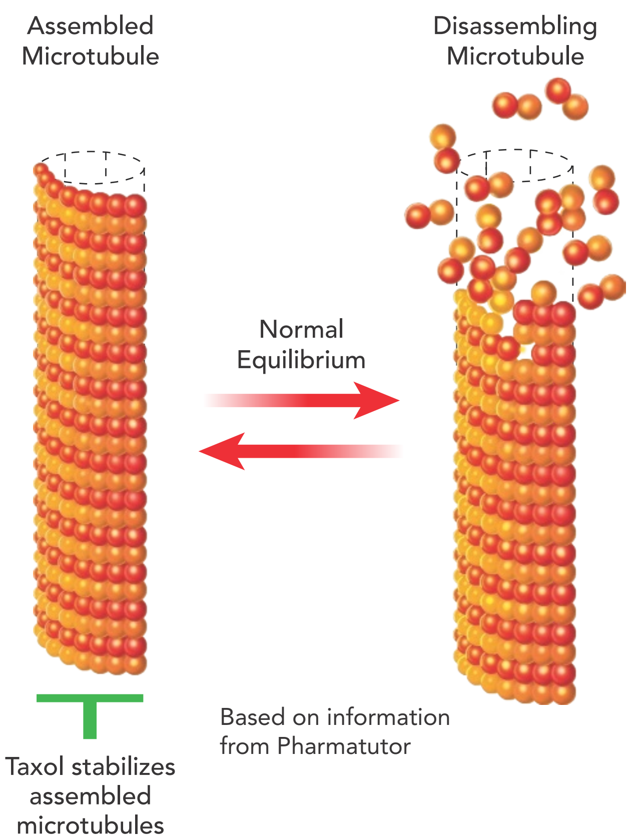
The drug taxol has become widely used to treat many kinds of cancer, especially breast cancer. The drug works by acting on microtubules. As you read in this chapter, during prophase and metaphase of mitosis, microtubules attach to the chromosomes and move them to the center of the cell. Then, during anaphase, microtubules disassemble, separating the chromosomes into two daughter cells.

Taxol works by binding to microtubule proteins, and preventing their disassembly. The result is that the cell is "stuck" in metaphase, cannot complete mitosis, and may undergo spontaneous cell death. Cancer cells divide especially rapidly, so taxol harms them more than it harms normal cells.

If you think that a drug that stops mitosis is acting like a poison, you may be correct. Taxol acts on normal cells and cancer cells alike. As a result, it has many side effects, including hair loss and reduced blood cell counts. Doctors try to prescribe taxol in just the right dosages to fight cancerous tumors while minimizing the damage it causes.

SCIENCE PROJECT

The drug Taxol is used to treat cancer. It is derived from the bark of the Pacific Yew, the tree shown here.



Based on information from Pharmatutor

1. **Interpret Visuals** Use the diagram to explain, in your own words, how taxol acts on microtubules.
2. **Defend Your Claim** Is it accurate to describe taxol as both a drug and a poison? Use logical reasoning to defend or support your answer.
3. **Construct an Explanation** Why is taxol useful for fighting cancer? (**Hint:** Review Lesson 3 for the definition of *cancer* and the examples of malignant tumors.)
4. **Conduct Research** What additional questions do you have about cancer and the drugs that fight this disease? Record your questions, and then conduct research to learn the answers or to find more information.
5. **Develop a Model** Choose one of the cancer drugs that you have researched. Draw a diagram or make a flowchart to show how the drug works and why it is useful. Share your model with your classmates.

CHAPTER 11

ASSESSMENT

KEY QUESTIONS AND TERMS

11.1 Cell Growth, Division, and Reproduction

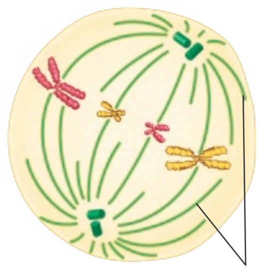
HS-LS1-4

1. The rate at which materials enter and leave the cell depends on the cell's
   a. volume.
   b. weight.
   c. speciation.
   d. surface area.
2. In order for a cell to divide successfully, the cell must first
   a. duplicate its genetic information.
   b. decrease its volume.
   c. increase its number of chromosomes.
   d. decrease its number of organelles.
3. The process that increases genetic diversity within a population is
   a. asexual reproduction.
   b. sexual reproduction.
   c. cell division.
   d. binary fission.
4. Describe what is meant by each of the following terms: *cell volume, cell surface area, ratio of surface area to volume.*
5. Describe asexual and sexual reproduction as survival strategies.

11.2 The Process of Cell Division

HS-LS1-4

6. Sister chromatids are attached to each other at an area called the
   a. centriole.
   b. centromere.
   c. spindle.
   d. chromosome.
7. If a cell has 12 chromosomes, how many chromosomes will each of its daughter cells have after mitosis and cytokinesis?
   a. 4 c. 12
   b. 6 d. 24
8. In plant cells, what forms midway between the divided nuclei during cytokinesis?
   a. nuclear membrane
   b. centromere
   c. cell membrane
   d. cell plate
9. Describe how a eukaryotic cell's chromosomes change as a cell prepares to divide.
10. What is the relationship between interphase and cell division?
11. List the following stages of mitosis in the correct sequence, and describe what happens during each stage: anaphase, metaphase, prophase, and telophase.
12. Identify the stage of mitosis shown here. Describe the events that occur in this stage.



11.3 Regulating the Cell Cycle

13. The timing in the cell cycle in eukaryotic cells is believed to be controlled by a group of closely related proteins known as
    a. chromatids.
    b. centromeres.
    c. cyclins.
    d. centrioles.
14. Which statement does NOT describe external regulatory proteins?
    a. They respond to events occurring inside a cell.
    b. Growth factors are one group of external regulatory proteins.
    c. They can speed up or slow down the cell cycle.
    d. Some can cause cells to slow down or stop their cell cycles.
15. How do cancer cells differ from noncancerous cells? How are they similar?

16. When some cells are removed from the center of a tissue culture, will new cells replace the cells that were removed? Explain.

17. Describe the role of cyclins.

11.4 Cell Differentiation

HS-LS1-4

18. Bone marrow cells that produce blood cells are best categorized as
   a. embryonic stem cells.
   b. adult stem cells.
   c. pluripotent cells.
   d. totipotent cells.

19. Which type of cell has the potential to develop into the widest variety of differentiated cells?
   a. totipotent
   b. pluripotent
   c. multipotent
   d. differentiated

20. What is a blastocyst?

21. What is cell differentiation? Make a drawing that illustrates the process.

22. Describe two ways that technology may address the ethical concerns related to stem cell research.

CRITICAL THINKING

HS-LS1-4

23. **Use Models** Two objects modeling cellular shapes are shown. All of the sides in Shape A are equal in size.

Compare the ratio of surface area to volume for the two objects. Then use your results to explain how the long, flattened shapes of some organisms, such as single-celled paramecia, help them survive.

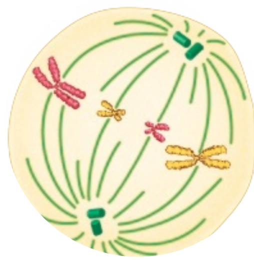
24. **Predict** A cell will usually undergo apoptosis if the cell experiences DNA damage that could lead to a tumor. Predict what may happen if a gene that controls apoptosis is damaged.

25. **Form a Hypothesis** A particular environment undergoes frequent changes. Which organisms are more likely to have an advantage in that environment—those that reproduce asexually or those that reproduce sexually? Explain your reasoning.

26. **Summarize** Create a flowchart that relates the following terms: *prophase*, *metaphase*, *anaphase*, *telophase*, and *cytokinesis*. Be sure to describe each phase and identify the relationships among them.

27. **Compare and Contrast** Differentiate between DNA replication in prokaryotes and DNA replication in eukaryotes.

28. **Use Models** The model shows a phase of mitosis.



   a. Determine whether this model represents a plant or an animal cell.
   b. The four chromosomes in the center of this cell each have two connected strands. Explain how the two strands on the same chromosome compare with regard to the genetic information they carry. Why is this important to the cell?

29. **Use Evidence to Construct an Argument** A researcher observes that some cells in a sample have several nuclei within their cytoplasm. Considering the events in a typical cell cycle, propose an argument to explain what could have occurred in these cells.

30. **Draw Conclusions** A scientist is developing a new cancer treatment. She is investigating a chemical that prevents DNA synthesis.
   a. In which stage of mitosis does the chemical act?
   b. Why would the chemical affect cancer cells more than normal cells?

CROSSCUTTING CONCEPTS

31. **Cause and Effect** The nerve cells in the human nervous system seldom undergo mitosis. How might this affect the recovery of an injury to the nervous system?

32. **Systems and System Models** Different models, such as that of a growing town, may be used to describe the relationship between the surface area of a cell and its volume. Develop a new model you could use to describe the cell system, and explain why the size of a cell is limited.

33. **Cause and Effect** Researchers discovered how to make skin stem cells pluripotent. Describe how this discovery affected research involving treatments for heart attack patients.

MATH CONNECTIONS

Analyze and Interpret Data

A scientist performed an experiment to determine the effect of temperature on the length of the cell cycle in onion cells. These data are summarized in the table. Use the data table to answer questions 34–36.

Effect of Temperature on Length of Onion Cell Cycle

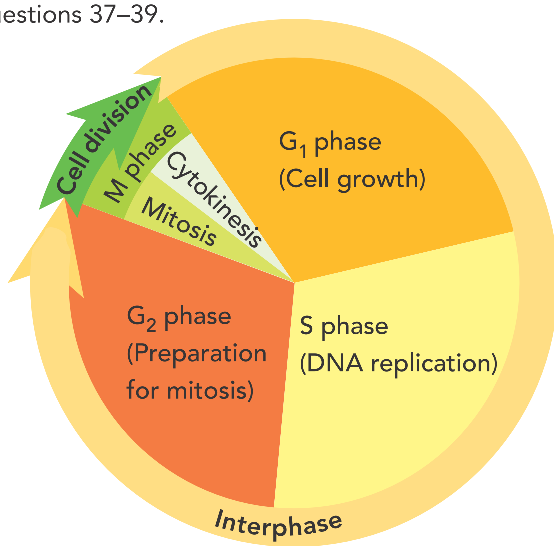
Temperature (°C)	Length of Cell Cycle (hours)
10	54.6
15	29.8
20	18.8
25	13.3

34. **Analyze Data** On the basis of the data in the table, how long would you expect the cell cycle to take at 5°C?
    a. less than 13.3 hours
    b. more than 54.6 hours
    c. between 29.8 and 54.6 hours
    d. about 20 hours

35. **Construct Graphs** Construct a line graph of the data in the table. Describe the shape of the graph.

36. **Interpret Tables** Given this set of data, what is one valid conclusion the scientist could state?

Use the diagram model of the cell cycle to answer questions 37–39.



37. **Use Models** Explain how the model represents the cell cycle. Discuss the circular shape of the model and the relative sizes of the regions for the phases.

38. **Revise Models** How could you revise the model to show the stages of mitosis?

39. **Calculate** A human cell has 46 chromosomes. After a cell passes through three rounds of the cell cycle, how many cells are formed? How many copies of chromosomes are in these cells? Assume that each cell divides to form two new daughter cells.

LANGUAGE ARTS CONNECTION

Write About Science

CCSS.ELA-LITERACY.WHST.9-10.2, CCSS.ELA-LITERACY.WHST.9-10.4

40. **Write Explanatory Texts** Write a paragraph explaining the cell cycle and its importance in living organisms.

41. **Produce Clear Writing** Differentiation is essential to multicellular organisms. Clearly describe a model that would illustrate differentiation.

Read About Science

CCSS.ELA-LITERACY.RST.9-10.5, CCSS.ELA-LITERACY.RST.9-10.10

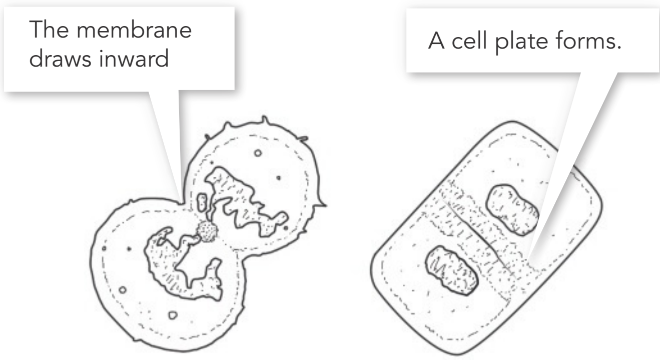
42. **Summarize Text** Reread the text under the heading Stem Cells and Development. In a brief paragraph, summarize the information you learned from reading this text.

43. **Analyze Text Structure** Review the content about the cell cycle and mitosis. Describe how the use of headings of different sizes and colors are used to make the content easier to understand.

END-OF-COURSE TEST PRACTICE

1. A cow has 60 chromosomes in each of its body cells. How does mitosis function to maintain this number of chromosomes?
   A. Chromosomes are replicated in interphase and separated in anaphase.
   B. Chromosomes are replicated in prophase and separated in telophase.
   C. Chromosomes are separated in anaphase and replicated in telophase.
   D. Chromosomes are replicated and separated into daughter cells during mitosis.
   E. Chromosomes are replicated during asexual reproduction and separated during sexual reproduction.

2. Cell division occurs in animal cells and plant cells. The illustration below shows an animal cell and a plant cell during the same phase of cell division.



Animal Cell **Plant Cell**

   Which of the following **best** describes this phase of cell division?
   A. The cells are completing the growth phase and entering prophase.
   B. The chromosomes in each cell have just replicated and the cells are entering mitosis.
   C. Mitosis has just begun and the chromosomes are condensing into chromatids.
   D. Mitosis is complete and the plant cell is forming a cell plate because plants have cell walls.
   E. The cells are in metaphase and the animal cell is drawing inward where chromosomes will line up for separation.

3. Cells from a plant leaf, root, and stem have different characteristics that can be observed when viewed under a microscope. How can cells from a single plant have different characteristics?
   A. The cells have a different number of chromosomes.
   B. The cells have differentiated to produce different cell types.
   C. The cells are in different phases of mitosis.
   D. The cells are produced by sexual reproduction.
   E. The cells divide into prokaryotes and eukaryotes.

4. Why is cell division a necessary process for cells to function?
   A. If cells don't divide then cells won't have enough DNA.
   B. Cell division is necessary for prokaryotic cells to differentiate into eukaryotic cells.
   C. If cells don't divide then the volume of the cells will be too small compared to the surface area of the cells.
   D. Cell division is necessary for sexual reproduction to produce genetically identical offspring.
   E. If cells continue to grow without dividing they won't be able to efficiently move nutrients across the cell membrane.

ASSESSMENT

For additional assessment practice, go online to access your digital course.

If You Have Trouble With...				
Question	1	2	3	4
See Lesson	11.2	11.2	11.3	11.1
Performance Expectation	HS-LS1-4	HS-LS1-4	HS-LS1-4	HS-LS1-4