

# 5.1 The Cell Cycle

**KEY CONCEPT** Cells have distinct phases of growth, reproduction, and normal functions.

## ▶ MAIN IDEAS

- The cell cycle has four main stages.
- Cells divide at different rates.
- Cell size is limited.

## VOCABULARY

**cell cycle**, p. 134

**mitosis**, p. 135

**cytokinesis**, p. 135



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**Connect** Many of life's little chores such as sweeping and dusting, are quietly satisfying and rather fun. Washing dishes by hand, however, is never fun, which is why some clever person made the dishwasher. This handy invention soaks, washes, and rinses your dishes to a spot-free, sanitary sparkle. You unload the dishes, and the machine is ready to start the cycle all over again. A cell goes through a cycle, too. This cycle of growth, DNA synthesis, and division is essential for an organism to grow and heal. If it goes out of control, abnormal cell growth may occur, resulting in cancer cells like those shown on the previous page.

## ▶ MAIN IDEA

### The cell cycle has four main stages.

Just as all species have life cycles, from tiny chihuahuas to massive beluga whales, cells also have a life cycle. The **cell cycle** is the regular pattern of growth, DNA duplication, and cell division that occurs in eukaryotic cells.

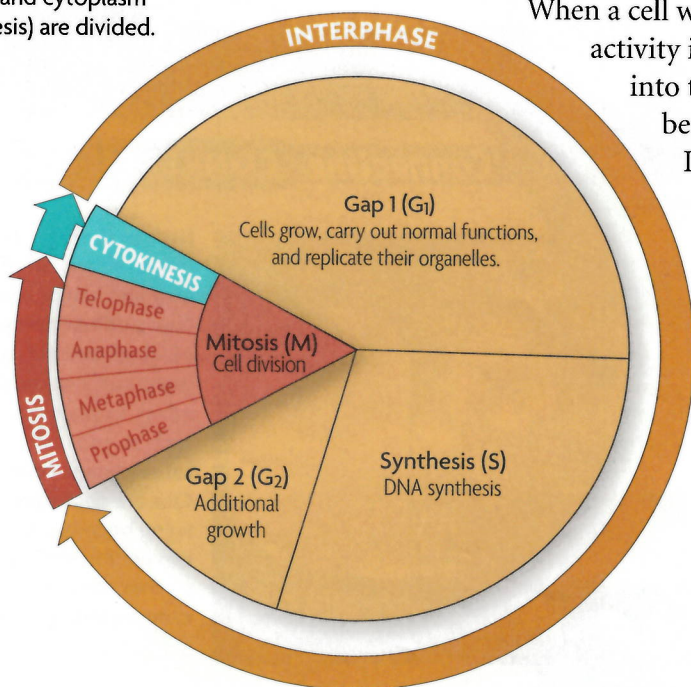
**FIGURE 5.1** shows its four main stages: gap 1, synthesis, gap 2, and mitosis. Gap 1, synthesis, and gap 2 together make up what is called interphase.

The stages of the cell cycle get their names from early studies of cell division. Scientists' observations were limited by the microscopes of the time.

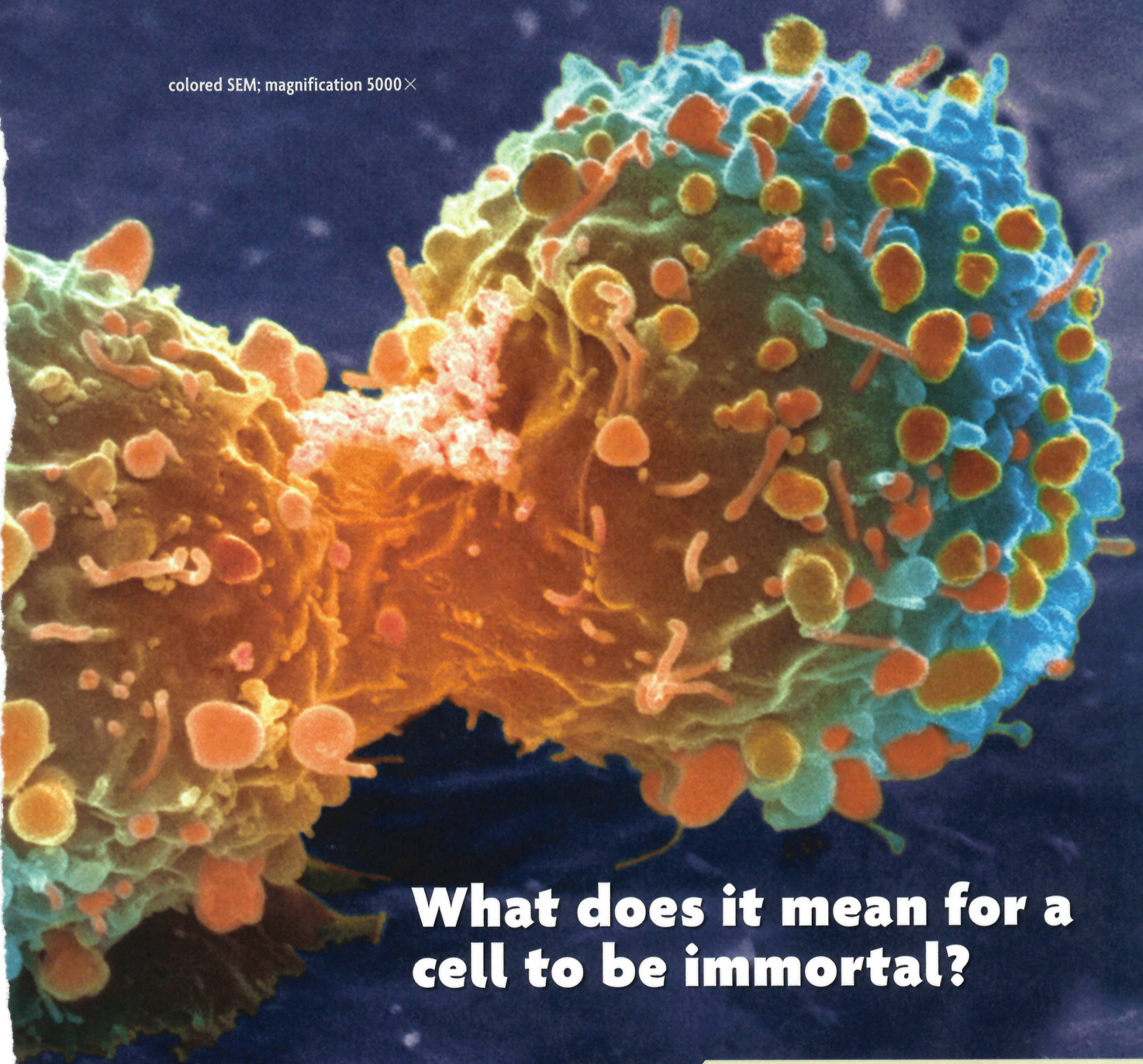
When a cell was not actively dividing, they could not see activity in it. Thus, they originally divided the cell cycle into two parts: interphase, when the cell appeared to be at rest, and mitosis, when the cell was dividing.

Improved techniques and tools later allowed scientists to detect the copying of DNA (DNA synthesis), and they changed their description of the cell cycle to include the synthesis stage. Since they still could not see anything happening during the other parts of interphase, scientists named the periods between mitosis and synthesis "gap 1" and "gap 2." Eventually, scientists learned that, during interphase, cells carry out their normal functions and undergo critical growth and preparation for cell division.

**FIGURE 5.1** Cells grow and copy their DNA during interphase. They also carry out cell-specific functions in G<sub>1</sub> and G<sub>2</sub>. During M stage, both the nucleus (in mitosis) and cytoplasm (in cytokinesis) are divided.



colored SEM; magnification 5000×



## What does it mean for a cell to be immortal?

### Connecting CONCEPTS

The photograph above shows a lung cancer cell undergoing cell division. Unlike healthy cells, cancer cells can divide without limit—they are what scientists call *immortal*. This property is useful to scientists who culture cancer cells for research purposes. However, cancer cells are very dangerous in the body, where they may form tumors and invade tissues.



**Human Biology** These photographs show half of a cancerous lung and half of a healthy lung. Gases diffuse across the surfaces of a healthy lung, so the membrane surfaces must be thin and moist. Exposure to substances such as tobacco smoke can cause changes in the lung cells. Cilia are destroyed, and the lung lining becomes thicker. The lungs can no longer clean themselves, so they are more susceptible to cancer-causing agents.

## Gap 1 (G<sub>1</sub>)

The first stage of the cell cycle is gap 1 (G<sub>1</sub>). During G<sub>1</sub>, a cell carries out its normal functions. If it is a skeletal muscle cell, it contracts to move joints. If it is an adrenal cell, it secretes hormones such as adrenaline. If it is an intestinal cell, it absorbs nutrients. During G<sub>1</sub>, cells also increase in size, and organelles increase in number. A cell spends most of its time in the G<sub>1</sub> stage, although the length of this stage varies by cell type.

During G<sub>1</sub>, the cell must pass a critical checkpoint before it can proceed to the synthesis stage. Just as it would be dangerous for you to run a marathon if you had not slept or eaten for several days, it would also be dangerous for your cells to continue dividing if certain conditions were not met. For instance, most animal cells need enough nutrition, adequate size, and relatively undamaged DNA to divide successfully. They also need specific signals from other cells, telling them whether more cell division is needed.

## Synthesis (S)

The second stage of the cell cycle is the synthesis (S) stage. *Synthesis* means “the combining of parts to make a whole.” During the S stage, the cell makes a copy of its nuclear DNA. In eukaryotes, DNA is located in the nucleus. During interphase, it is loosely organized and appears grainy in photographs. By the end of the S stage, the cell nucleus contains two complete sets of DNA.

## Gap 2 (G<sub>2</sub>)

Gap 2 (G<sub>2</sub>) is the third stage of the cell cycle. During G<sub>2</sub>, cells continue to carry out their normal functions, and additional growth occurs. Like G<sub>1</sub>, this stage includes a critical checkpoint. Everything must be in order—adequate cell size, undamaged DNA—before the cell goes through mitosis and division.

## Mitosis (M)

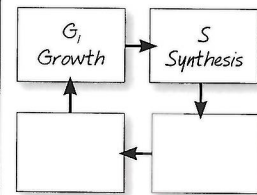
Mitosis (M), the fourth stage of the cell cycle, includes two processes: mitosis and cytokinesis. **Mitosis** (my-TOH-sihs) is the division of the cell nucleus and its contents. During mitosis, the nuclear membrane dissolves, the duplicated DNA condenses around proteins and separates, and two new nuclei form. Lastly, **cytokinesis** (SY-toh-kuh-NEE-sihs) is the process that divides the cell cytoplasm. The result is two daughter cells that are genetically identical to the original cell.

The stages of the cell cycle and the proteins that control it are similar in all eukaryotes. For example, scientists have demonstrated that some of the molecules that regulate checkpoints in the yeast cell cycle can work in human cells, too. Such similarities suggest that eukaryotes share a common ancestry.

**Predict** What might happen if the G<sub>2</sub> checkpoint stopped working in cells?

## TAKING NOTES

Construct your own cycle diagram to take notes about processes such as the cell cycle.

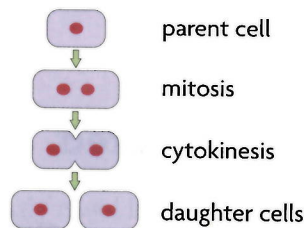


## Connecting CONCEPTS

**DNA replication** As you will learn in Chapter 8, DNA synthesis is also called DNA replication. During this process, the DNA molecule unzips and each strand is used as a pattern for a new DNA strand.

## VISUAL VOCAB

**Mitosis** is the division of the cell nucleus and its contents.



**Cytokinesis** divides the cell cytoplasm.



Multicellular organisms use cell division for growth and repair.

**FIGURE 5.2 CELL LIFE SPAN**

CELL TYPE	APPROXIMATE LIFE SPAN
Skin cell	2 weeks
Red blood cell	4 months
Liver cell	300–500 days
Intestine—internal lining	4–5 days
Intestine—muscle and other tissues	16 years

Source: Spaulding et al., *Cell* 122:1.

### Connecting CONCEPTS

**Lymphocytes** As you will learn in Chapter 31, lymphocytes are a part of your immune system. There are two major types of lymphocytes, B and T cells. Both types recognize specific antigens.

## ▶ MAIN IDEA

### Cells divide at different rates.

Rates of cell division vary widely, as shown in **FIGURE 5.2**. The prokaryotic cell cycle is similar but not identical to that of eukaryotic cells. Recall that prokaryotes do not have the membrane-bound organelles and cytoskeleton found in eukaryotes. Thus, prokaryotic cells typically divide much faster than do eukaryotic cells.

The rate at which your cells divide is linked to your body's need for those cells. In human cells, the S, G<sub>2</sub>, and M stages together usually take about 12 hours. The length of the G<sub>1</sub> stage differs most from cell type to cell type. The rate of cell division is greater in embryos and children than it is in adults. Their cell cycle is shorter, and many of their organs are still developing. But the rate of cell division also varies within different tissues of the adult body. The internal lining of your digestive tract receives a lot of wear and tear. As a result, cells that line your stomach and intestine are replaced every few days. In contrast, cells that make up the rest of your intestine

(mainly smooth muscle) and many of your internal organs, such as lungs, kidney, and liver, divide only occasionally, in response to injury or cell death.

Cells that divide only rarely are thought to enter a stage that some scientists call G<sub>0</sub>. In G<sub>0</sub>, cells are unlikely to divide, although they continue to carry out their normal functions. Some cells, such as neurons, appear to stay permanently in the G<sub>0</sub> stage. However, some data suggest that neurons actually can divide, and this question continues to be actively researched. Other cells, such as lymphocytes, a type of white blood cell, may remain in G<sub>0</sub> for years until they recognize an invader. Once the invader binds to a lymphocyte receptor, the lymphocyte goes through rapid cell divisions to help fight infection.

**Infer** Do you think a skin cell would have a long or short G<sub>1</sub> stage? Explain why.

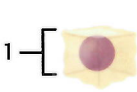
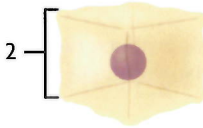
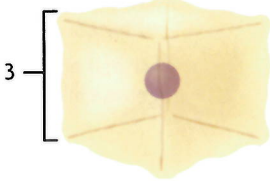
## ▶ MAIN IDEA

### Cell size is limited.

Cells have upper and lower size limits. If cells were too small, they could not contain all of the necessary organelles and molecules. For instance, a cell with too few mitochondria would not have enough energy to live. Nor can cells grow beyond a certain size, even if surrounded by plenty of nutrients. The upper limit on cell size is due to the ratio of cell surface area to volume. Recall that oxygen, nutrients, and wastes move across the cell membrane, or the surface of the cell. These materials must be transported in adequate amounts and with adequate speed to keep the inside of the cell functioning. But as a cell increases in size, its volume increases faster than its surface area, as shown in **FIGURE 5.3**. Therefore, a further increase in size could result in a surface area too small for the adequate exchange of materials.

## FIGURE 5.3 Ratio of Surface Area to Volume in Cells

As a cell grows, its volume increases more rapidly than its surface area. When the surface area-to-volume ratio is too small, the cell cannot move materials into and out of the cell at a sufficient rate or in sufficient quantities.

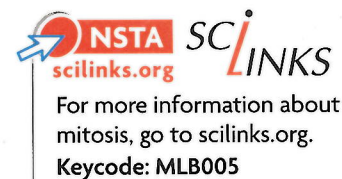
Relative size			
Surface area (length × width × number of sides)	6	24	54
Volume (length × width × height)	1	8	27
Ratio of surface area to volume	$\frac{6}{1} = 6:1$	$\frac{24}{8} = 3:1$	$\frac{54}{27} = 2:1$

**Compare** Which cell has the largest surface area? Which cell has the largest surface area to volume ratio?

Some cells, however, must be large. A neuron running down a giraffe's neck to its legs may be several meters long, for instance. But it is not shaped like a cube or a sphere. Instead, it is extremely long and thin. This structure gives the neuron a large surface area with a relatively small increase in volume.

To maintain a suitable cell size, growth and division must be coordinated. If a cell more than doubled its size before dividing, the daughter cells would be larger than the original cell. If this happened each generation, cells would quickly become too large to live. Similarly, if a cell did not double its size before dividing, the daughter cells would be smaller than the original cell. If this happened each generation, cells would quickly become too small to live.

**Connect** Which has the larger ratio of surface area to volume, a tennis ball or a soccer ball? Explain your reasoning.



## 5.1 ASSESSMENT



### REVIEWING MAIN IDEAS

1. During which stage of the **cell cycle** is the DNA copied?
2. Which stages of the cell cycle generally require about the same amount of time in all human cells?
3. What limits the maximum size of a cell?

### CRITICAL THINKING

4. **Infer** Suppose you were to draw a diagram representing the cell cycle of a neuron. Explain where and how you would represent  $G_0$ .
5. **Predict** Suppose you treat cells with chemicals that block **cytokinesis**. Describe what you think the cells would look like.

### Connecting CONCEPTS

6. **Scientific Process** Predict how the rate of cell division would differ between single-celled algae living in a sunny, nutrient-rich pond versus algae living in a shady, nutrient-poor pond. How could you test your prediction?

# 5.2

# Mitosis and Cytokinesis

**KEY CONCEPT** Cells divide during mitosis and cytokinesis.

## ▶ MAIN IDEAS

- Chromosomes condense at the start of mitosis.
- Mitosis and cytokinesis produce two genetically identical daughter cells.

## VOCABULARY

<b>chromosome</b> , p. 138	<b>telomere</b> , p. 139
<b>histone</b> , p. 139	<b>prophase</b> , p. 140
<b>chromatin</b> , p. 139	<b>metaphase</b> , p. 140
<b>chromatid</b> , p. 139	<b>anaphase</b> , p. 140
<b>centromere</b> , p. 139	<b>telophase</b> , p. 140



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**Connect** When you were a child, perhaps you attended a birthday party where goody bags were handed out. Whoever stuffed the bags had to make sure that each bag had exactly the same number of erasers, candies, and stickers. Otherwise, some ill-mannered child (not you, of course) might have raised a fuss if an item was missing. In a similar way, your cells must receive a full set of DNA—no more, no less—to work properly. Dividing DNA is a complicated task because the DNA is so long and stringy. Mitosis is an amazing process that efficiently sorts two sets of DNA and divides them between two nuclei.

## ▶ MAIN IDEA

### Chromosomes condense at the start of mitosis.

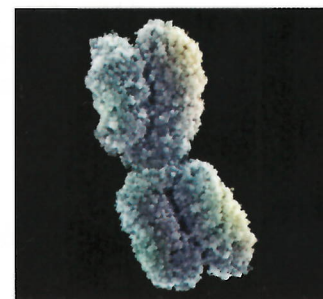
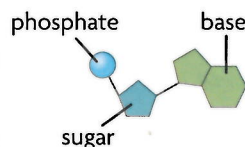
DNA is a double-stranded molecule made of four different subunits called nucleotides. A **chromosome** is one long continuous thread of DNA that consists of numerous genes along with regulatory information. Your body cells have 46 chromosomes each. If stretched out straight and laid end to end, the DNA in just one of your cells would be about 3 meters (10 feet) long. How does it fit inside the nucleus of a microscopic cell?

DNA wraps around proteins that help organize and condense it. During interphase, or when a cell is not dividing, DNA is loosely organized—it looks a bit like spaghetti. During mitosis, however, your chromosomes are tightly condensed, as shown in **FIGURE 5.4**. These changes in DNA's organization allow a cell to carry out its necessary functions. During all of interphase, proteins must access specific genes for a cell to make specific proteins or to copy the entire DNA sequence. During mitosis, the duplicated chromosomes must condense to be divided between two nuclei.

If chromosomes remained stringy during mitosis, they could become entangled. Perhaps a cell would get two copies of one chromosome and no copies of a different one. **FIGURE 5.5** shows the process that converts a chromosome from a linear strand of DNA to its highly condensed form. The key to this process is the association between DNA and proteins.

## Connecting CONCEPTS

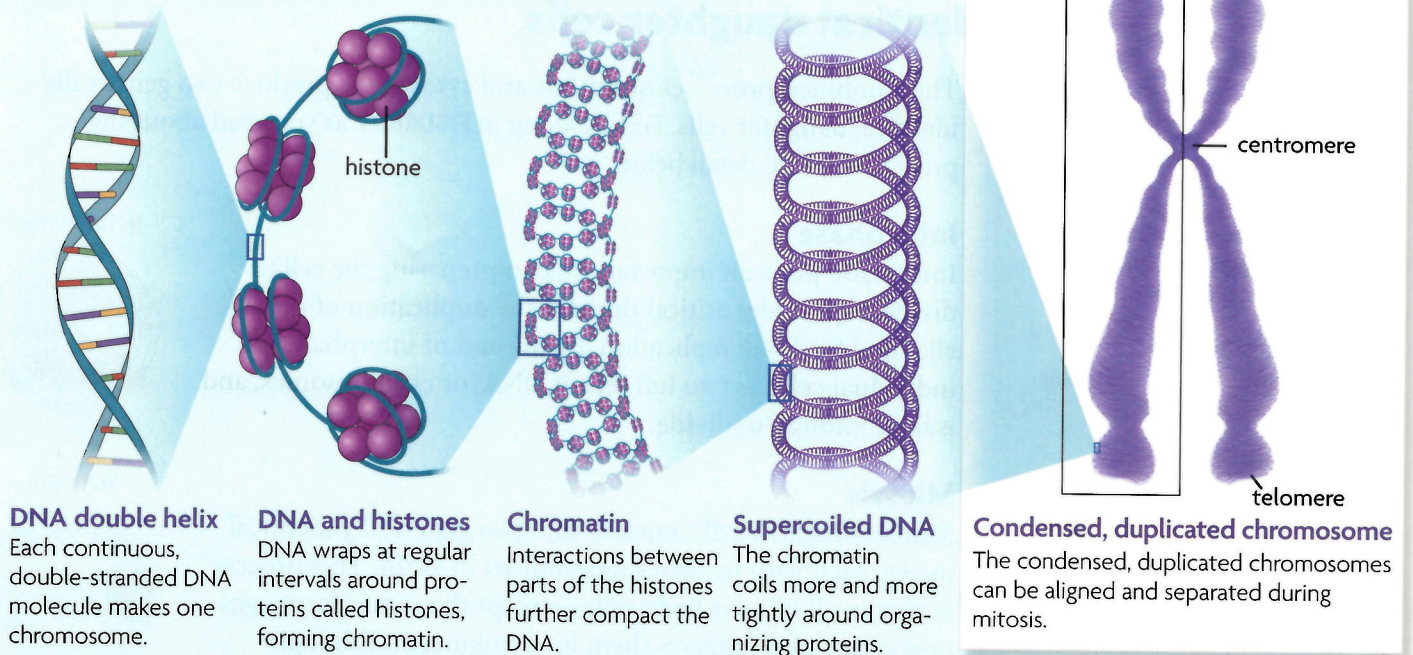
**Biochemistry** As you will learn in **Chapter 8**, a nucleotide is made of three parts: a sugar, a phosphate group, and a nitrogen-containing molecule called a base. When the sugars and phosphate groups bond, they form the backbones of the long chains called nucleic acids.



**FIGURE 5.4** This duplicated chromosome is tightly condensed. (colored SEM; magnification unknown)

## FIGURE 5.5 Chromosome Structure

DNA condenses tightly during the early stages of mitosis.



### DNA double helix

Each continuous, double-stranded DNA molecule makes one chromosome.

### DNA and histones

DNA wraps at regular intervals around proteins called histones, forming chromatin.

### Chromatin

Interactions between parts of the histones further compact the DNA.

### Supercoiled DNA

The chromatin coils more and more tightly around organizing proteins.

### Condensed, duplicated chromosome

The condensed, duplicated chromosomes can be aligned and separated during mitosis.

**Infer** Overall, DNA has a negative charge. Look at the histone proteins in the figure. What type of overall charge do you think they have? Explain.

At almost all times during the cell cycle, each of your chromosomes is associated with a group of proteins called **histones**. DNA wraps around histones at regular intervals, similar to beads on a string. Parts of the histones interact with each other, further compacting the DNA. At this stage—the “spaghetti” stage—the loose combination of DNA and proteins is called **chromatin**. The word “loose” describes how much the DNA strand folds back on itself; it does not mean the DNA is loosely wrapped around the histones.

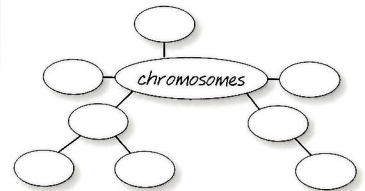
As a cell progresses into mitosis, chromatin further condenses. It continues to coil more and more tightly around organizing proteins, finally forming small thick rods. Recall that each chromosome has already been copied during the previous S stage. Thus, the chromosome looks similar to an “X” in which the left and right halves are two identical DNA double helices. One half of a duplicated chromosome is called a **chromatid** (KROH-muh-tihd). Together, the two identical chromatids are called sister chromatids. Sister chromatids are held together at the **centromere** (SEHN-truh-MEER), a region of the condensed chromosome that looks pinched.

In addition, the ends of DNA molecules form structures called **telomeres** (TEHL-uh-mærs), which are made of repeating nucleotides that do not form genes. They prevent the ends of chromosomes from accidentally attaching to each other, and they help prevent the loss of genes. A short section of nucleotides is lost from a new DNA molecule each time it is copied. It is important that these nucleotides are lost from telomeres, not from the genes themselves.

**Apply** What is the relationship between a molecule of DNA and a chromosome?

### TAKING NOTES

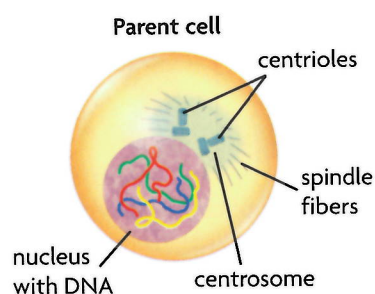
Use a main idea web to help you study the makeup and organization of chromosomes.



## ▶ MAIN IDEA

# Mitosis and cytokinesis produce two genetically identical daughter cells.

**FIGURE 5.6** The nucleus and chromosomes go through dramatic changes in a dividing cell.



## Connecting CONCEPTS

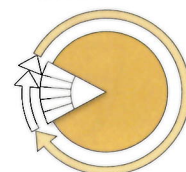
**Cells** As you will learn in Chapter 6, your body has two major cell types. Germ cells develop into eggs or sperm. Somatic cells make up the rest of your body.

The combined processes of mitosis and cytokinesis produce two genetically identical daughter cells. Follow along in **FIGURE 5.7** as you read about the process in more detail below.

## Interphase

Interphase plays an important role in preparing the cell to divide. It provides critical time for the duplication of organelles and for DNA replication. By the end of interphase, an individual cell has two full sets of DNA, or chromosomes, and is large enough to divide.

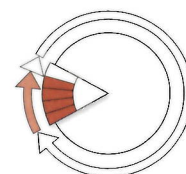
### INTERPHASE



## Mitosis

Mitosis divides a cell's nucleus into two genetically identical nuclei, each with its own single, full set of DNA. This process occurs in all of your body cells—except those that form eggs or sperm—and prepares them for cytokinesis. Although mitosis and cytokinesis are continuous processes, scientists have divided them into phases to make them easier to understand and discuss. The four main phases of mitosis are prophase, metaphase, anaphase, and telophase. Cytokinesis begins during late anaphase or telophase.

### MITOSIS

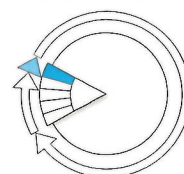


- 1 During **prophase**, chromatin condenses into tightly coiled chromosomes. Each consists of two identical sister chromatids. The nuclear envelope breaks down, the nucleolus disappears, and the centrosomes and centrioles begin to migrate to opposite sides of the cell. Organized microtubules called spindle fibers grow from the centrioles and radiate toward the center of the cell.
- 2 In **metaphase**, the spindle fibers attach to a protein structure on the centromere of each chromosome and align the chromosomes along the cell equator, around the middle of the cell.
- 3 During **anaphase**, sister chromatids separate from each other. The spindle fibers begin to shorten, which pulls the sister chromatids away from each other and toward opposite sides of the cell.
- 4 In **telophase**, a complete set of identical chromosomes is positioned at each pole of the cell. The nuclear membranes start to form, the chromosomes begin to uncoil, and the spindle fibers fall apart.

## Cytokinesis

Cytokinesis divides the cytoplasm into two cells and completes a full stage of the cell cycle. Cytokinesis differs in animal and plant cells. In animal cells, the membrane forms a furrow, or trench, that is pulled inward by tiny filaments, like a drawstring. Gradually, the membrane pinches closed, forming a separate cell around each nucleus.

### CYTOKINESIS





## FIGURE 5.7 The Cell Cycle in Detail

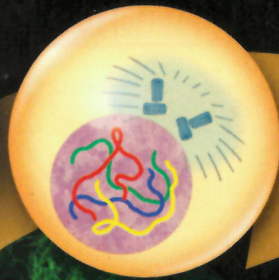
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in action at  
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Following interphase, mitosis divides duplicated chromosomes between two nuclei. Cytokinesis divides the cytoplasm. In this diagram, the mitosis stage is greatly expanded to highlight its four major phases. (micrographs; magnification about 100 $\times$ )

### INTERPHASE

The cell copies its DNA and grows in preparation for division. The DNA is loosely organized during interphase.



### MITOSIS

Mitosis divides a cell's nucleus into two nuclei, each with an identical set of DNA.



- 1 Prophase** DNA and proteins condense into tightly coiled chromosomes. The nuclear envelope breaks down, centrioles begin to move to opposite poles, and spindle fibers form.

### CYTOKINESIS

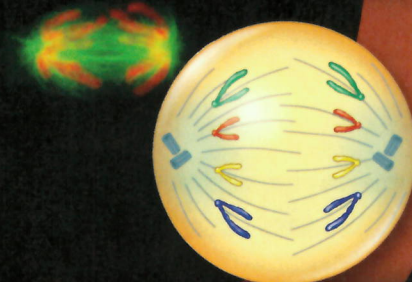
Cytokinesis divides cytoplasm between two daughter cells, each with a genetically identical nucleus. The cells enter interphase and begin the cycle again.



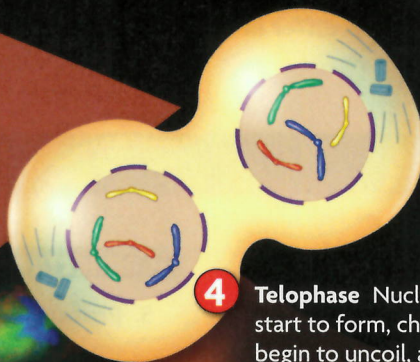
- 2 Metaphase** Spindle fibers attach to each chromosome. They align the chromosomes along the cell equator.



- 3 Anaphase** Chromatids separate to opposite sides of the cell. Cytokinesis usually begins in late anaphase or telophase.



- 4 Telophase** Nuclear membranes start to form, chromosomes begin to uncoil, and the spindle fibers fall apart.



### CRITICAL VIEWING

How many chromosomes does the cell have at the start of mitosis? How many does it have after cytokinesis?

## DATA ANALYSIS

### CONSTRUCTING DATA TABLES

Scientists use data tables to record their data. Data tables are organized by the independent and dependent variables. Usually the independent variable is listed in the left column, and the other columns list the dependent variables. Each separate observation is listed in its own row. When measurements are taken using units, they are listed in the column headings in parentheses. All tables should have numbers and titles.

Table 1 shows data from a hypothetical experiment in which growth hormones were added to clumps of cells in a laboratory, and the growth of the cell clumps was measured.

TABLE 1. EFFECT OF HORMONES ON CELL DIVISION

Concentration of Hormone Solution (%)	Size of Cell Clump After 24 Hours (mm)
0	3
25	4
50	8
75	9
100	9

Labels in the diagram: 'independent variable' points to the first column, 'dependent variable' points to the second column, and 'observations' points to the rows of data.

- 1. Display Data** Suppose a scientist decided to measure the effect of temperature on cell division in *chlorella*, a type of green algae. Set up a table that could be used to record the results for the number of daily doublings of the cells: 20°C, 3 doublings; 30°C, 7 doublings; 40°C, 12 doublings; 50°C, 0 doublings.
- 2. Apply** Label the independent and dependent variables on your table.

During cytokinesis in plant cells, the membrane cannot pinch inward because of the cell wall. Instead, a cell plate forms between the two nuclei. It is made by the Golgi apparatus, which supplies the new plasma membrane. A new wall then grows as cellulose and other materials are laid down. Typically, cytoplasm is divided evenly between daughter cells in both plant and animal cells.

The formation of new cells is critical in both multicellular and single-celled organisms. Single-celled organisms use cell division to reproduce, whereas multicellular organisms use it for growth, development, and repair.

**Contrast** How does cytokinesis differ in animal and plant cells?

## 5.2 ASSESSMENT



### REVIEWING MAIN IDEAS

1. Draw what a **chromosome** looks like during **metaphase**. Identify the **chromatids** and the **centromere**.
2. Briefly explain why the daughter cells resulting from mitosis are genetically identical to each other and to the original cell.

### CRITICAL THINKING

3. **Contrast** How do **prophase** and **telophase** differ?
4. **Apply** Using a light microscope, you observe a cell that has no nucleus. What features would you look for to determine whether it is a eukaryotic cell undergoing mitosis or a prokaryotic cell?

### Connecting CONCEPTS

5. **Protein Synthesis** For a cell to make proteins, enzymes must access its genes. When **histones** are modified with acetyl groups ( $-\text{COCH}_3$ ), their positive charge is neutralized, so they wrap DNA less tightly. How might this affect the rate of protein synthesis?

**MATERIALS**

- slides of onion root cells
- microscope

**PROCESS SKILLS**

- **Observing**
- **Collecting Data**
- **Concluding**

## Mitosis in Onion Root Cells

In this lab, you will examine cells from onion root tissue under the microscope and identify the different stages of cell division. You will also determine how much time is spent in each stage of the cell cycle.

**PROBLEM** How much time do cells spend in each part of the cell cycle?

**PROCEDURE**

1. Obtain a slide of onion root cells. Examine the slide under the microscope using the low-power lens.
2. Find examples of cells in each stage of the cell cycle, including interphase and the stages of mitosis—prophase, metaphase, anaphase, and telophase. Draw and label each cell. Label structures within the cell.
3. Select a random area of the slide to study using the high-power lens.
4. Identify and record the stage of each cell in the view. Make a data table, like the one shown below, and record your data.
5. Repeat step 3 two more times.
6. Calculate the percentage of cells in each part of the cell cycle for each sample.

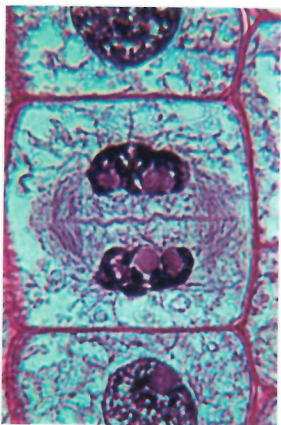
Sample	Total Cells	Interphase		Prophase		Metaphase		Anaphase		Telophase	
		No.	%	No.	%	No.	%	No.	%	No.	%
1											
2											
3											

**ANALYZE AND CONCLUDE**

1. **Analyze** What patterns exist in your data? In which stage of the cell cycle are most of the cells you examined? How do these data support what you know about the cell cycle?
2. **Calculate** Find the average percentage of cells in each stage of the cell cycle among the three samples. Assume that a cell takes 24 hours to complete one cell cycle. Calculate how much time is spent in each stage of the cell cycle. (**Hint:** Multiply the percentage of cells in each stage, as a decimal, by 24 hours.)
3. **Apply** The cells in the root of an onion are actively dividing. How might the numbers you count here be different than if you had examined cells from a different part of the plant?
4. **Predict** A chemical company is testing a new product that it believes will increase the growth rate of food plants. Suppose you are able to view the slides of onion root tips that have been treated with the product. If the product is successful, how might the slides look different from the slides you viewed in this lab? Draw some examples of what the treated slides might look like.

**EXTEND YOUR INVESTIGATION**

Design an experiment that would test the product described in question 4. Assume the product is a liquid that can be added to the soil in which the plant is growing.



This onion cell lays down a cell plate (middle) that will form new cell membranes and the cell wall. (LM, magnification 570 $\times$ )

# 5.3

## Regulation of the Cell Cycle

**KEY CONCEPT** Cell cycle regulation is necessary for healthy growth.

### ▶ MAIN IDEAS

- Internal and external factors regulate cell division.
- Cell division is uncontrolled in cancer.

### VOCABULARY

**growth factor**, p. 144

**apoptosis**, p. 145

**cancer**, p. 146

**benign**, p. 146

**malignant**, p. 146

**metastasize**, p. 146

**carcinogen**, p. 146



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**Connect** Have you ever watched a movie in which people play with the elements of nature? They might bring back dinosaurs or make a newfangled robot. And have you noticed that these movies are always scary? That's because things go out of control. The robots take over, or the dinosaurs start eating humans. If cell growth goes out of control in your body, the result can be even scarier. Cancer is uncontrolled cell growth and results from many factors that affect the cell cycle. So how does your body regulate all the millions of cell divisions happening in your body?

### ▶ MAIN IDEA

## Internal and external factors regulate cell division.

Both external and internal factors regulate the cell cycle in eukaryotic cells. External factors come from outside the cell. They include messages from nearby cells and from distant parts of the organism's body.

Internal factors come from inside the cell and include several types of molecules found in the cytoplasm. Both types of factors work together to help your body control the process of cell division.

### External Factors

External factors that help regulate the cell cycle include physical and chemical signals. One example of a physical signal is cell–cell contact. Most mammal cells grown in the laboratory form a single layer on the bottom of a culture dish, as shown in **FIGURE 5.8**. Once a cell touches other cells, it stops dividing. The exact reason for this phenomenon is unknown. One hypothesis is that receptors on neighboring cells bind to each other and cause the cells' cytoskeletons to form structures that may block the signals that trigger growth.

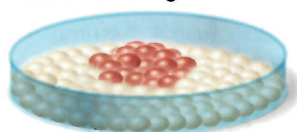
Many cells also release chemical signals that tell other cells to grow. For example, **growth factors** are a broad group of proteins that stimulate cell division. Growth factors bind to receptors that activate specific genes to trigger cell growth. In general, cells grow and divide in response to a combination of different growth factors, not just one.

**FIGURE 5.8** Normal animal cells (top) respond to external factors and stop dividing when they touch each other. Cancer cells (bottom) fail to respond and form clumps.

Normal cell growth



Cancerous cell growth



Some growth factors affect many different types of cells. For example, platelets are sticky fragments of bone marrow cells. They form clots that help stop bleeding. Platelets store a type of growth factor that helps your body repair wounds by triggering the growth of many different cell types. Other growth factors have more specific targets. For instance, erythropoietin (ih-RIHTH-roh-poy-EE-tihn) stimulates the production only of cells that will become red blood cells. Red blood cells carry oxygen. If you moved from the coast to the mountains, your blood oxygen levels would be lower because the air pressure is lower at higher altitudes. The decrease in blood oxygen levels would cause your body to produce more erythropoietin. That factor would increase the number of red blood cells and raise your blood oxygen levels.

Various hormones may also stimulate the growth of certain cell types. In particular, growth hormone results in bone growth and also affects your protein and fat metabolism.

### Internal Factors

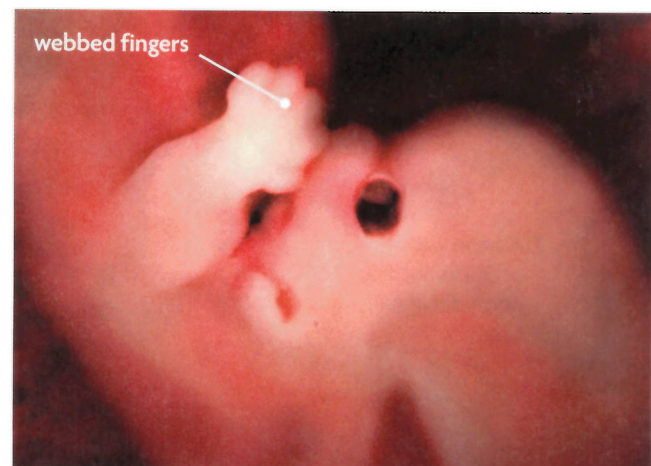
When external factors bind to their receptors, they can trigger internal factors that affect the cell cycle. Two of the most important and well-studied internal factors involved in the eukaryotic cell cycle are kinases and cyclins. A kinase is an enzyme that, when activated, transfers a phosphate group from one molecule to a specific target molecule. This action typically increases the energy of the target molecule or changes its shape. Your cells have many types of kinases, and they are almost always present in the cell. Those kinases that help control the cell cycle are activated by cyclins. Cyclins are a group of proteins that are rapidly made and destroyed at certain points in the cell cycle. These two factors help a cell advance to different stages of the cell cycle when cells bind to each other.

### Apoptosis

Just as some cells need to grow and divide, other cells need to die. **Apoptosis** (AP-uhp-TOH-sihs) is programmed cell death. It occurs when internal or external signals activate genes that help produce self-destructive enzymes. Many questions remain about this process. What is known is that the nucleus of an apoptotic cell tends to shrink and break apart, and the cell is recognized by specialized cells in the immune system. These cells very tidily gobble up the apoptotic cell and recycle its chemical parts for use in building other molecules. **FIGURE 5.9** shows a classic example of apoptosis. In the early stages of development, human embryos have webbing between their fingers and toes, or digits. Before a baby is born, those cells typically go through apoptosis. Most babies are born with little unwebbed fingers and toes they love to put in their mouths.

**Predict** Suppose a child was born whose receptors for growth hormone did not work properly. How do you think this would affect the child's development?

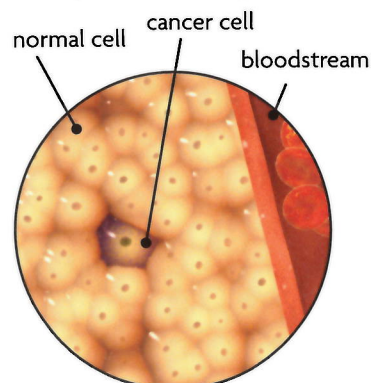
**FIGURE 5.9** Human embryos have webbed digits early in their development. The cells between the digits undergo apoptosis during later stages of development. As a result, the baby is born with unwebbed fingers and toes.



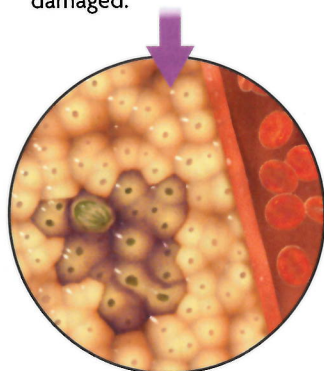
▶ MAIN IDEA

## Cell division is uncontrolled in cancer.

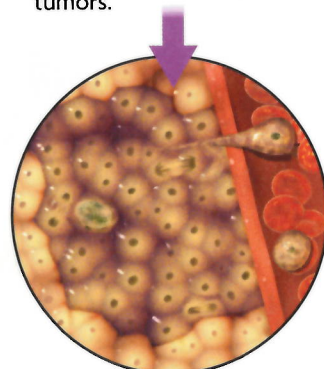
**FIGURE 5.10** Cancer cells form tumors that may metastasize to other parts of the body.



1. A healthy cell may become a cancer cell if certain genes are damaged.



2. Cancer cells divide more often than do healthy cells and may form disorganized clumps called tumors.



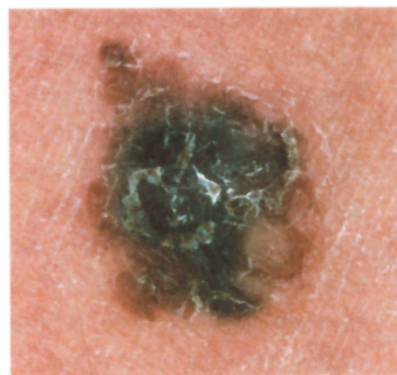
3. Sometimes, cancer cells break away from the tumor. They can be carried in the bloodstream to other parts of the body, where they form new tumors.

**Cancer** is the common name for a class of diseases characterized by uncontrolled cell division. It arises when regulation of the cell cycle breaks down. Unlike healthy cells, cancer cells grown in a culture dish continue to divide, even when surrounded by neighboring cells. Cancer cells can also continue to divide in the absence of many of the growth factors required for division in healthy cells. As a result, they divide much more often than do healthy cells.

Cancer cells form disorganized clumps called tumors. In a **benign** tumor, the cancer cells typically remain clustered together. This means the tumor may be relatively harmless and can probably be cured by removing it. However, if a tumor is **malignant**, some of the cancer cells can break away, or **metastasize** (mih-TAS-tuh-syz), from the tumor. These breakaway cells can be carried in the bloodstream or lymph system to other parts of the body, as shown in **FIGURE 5.10**, where they can form more tumors, called metastases. Once a tumor metastasizes, it is much more difficult to entirely rid the body of tumors.

But why are tumors harmful? Cancer cells do not perform the specialized functions needed by the body. In the lung, for example, cancer cells do not exchange oxygen and carbon dioxide. In the brain, they do not transmit the carefully ordered electrical messages needed to interpret information. Therefore, the body has large clumps of rapidly dividing cells that require lots of food and a hearty blood supply but that contribute nothing to the body's function. In addition, a growing tumor can exert great pressure on surrounding organs. For instance, a tumor growing inside the skull will cramp the brain for space, and some regions will be unable to function properly. If cancer cells continue to grow unchecked, they will eventually kill the organism.

Cancer cells come from normal cells that have suffered damage to the genes that help make proteins involved in cell-cycle regulation. Most cancer cells carry mutations, or errors, in two types of genes. One type, called oncogenes, accelerate the cell cycle. The second type act as cell-cycle brakes. Mutations in these genes can be inherited. For instance, some breast cancers appear to be caused by inherited errors in specific genes. Other mutations can be caused by exposure to radiation or chemicals. For example, some skin cancers are due to DNA damage caused by ultraviolet radiation from sunlight. Substances known to produce or promote the development of cancer are called **carcinogens** (kahr-SIHN-uh-juhonz). These include tobacco smoke and certain air pollutants, which are both associated with lung cancer. Some mutated forms of oncogenes are even carried by viruses; one such virus can cause cervical cancer.



**FIGURE 5.11** This cancerous mole is an example of a skin cancer, which may metastasize quickly.

## Cancer

In this lab, you will compare normal cells with cancerous cells and observe the differences between them.

**PROBLEM** How do normal and cancerous cells compare?

### PROCEDURE

1. Examine the slides of normal cells under the microscope. Draw and describe your observations.
2. Repeat step 1 with slides of cancer cells.

### ANALYZE AND CONCLUDE

1. **Compare** How does the structure of the normal cells compare with the structure of the cancerous cells for each of the slides you viewed?
2. **Infer** Cancer cells not only appear different from normal cells but they also divide more rapidly. Why do you think chemotherapy, a common treatment for cancer, results in the loss of hair?

### MATERIALS

- microscope
- slides of normal cells
- slides of cancerous cells

Standard cancer treatment often involves both radiation and chemotherapy. Radiation therapy is the use of radiation to kill cancer cells and shrink tumors. It works by damaging a cell's DNA so much that the cell cannot divide. Radiation is usually localized—that is, its use is targeted to a specific region—because it can also hurt healthy cells. Chemotherapy uses certain drugs, often in combination, to kill actively dividing cells. Like radiation, it kills both cancerous and healthy cells. However, chemotherapy is systemic—drugs travel throughout the entire body.

Medical researchers use laboratory-grown cancer cells in their search for cancer treatments. Much of what is known about the cell cycle has come from studies that use cancer cells. The most famous cancer cells used for research are called HeLa cells. HeLa cells were originally obtained in 1951 from a cervical tumor removed from a woman named Henrietta Lacks. This cell line continues to be grown and studied in laboratories all over the world.

**Analyze** HeLa cells are also used to study cell signaling processes. What might be a disadvantage of using cancer cells to study processes occurring in healthy cells?

## 5.3 ASSESSMENT

ONLINE QUIZ  
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### REVIEWING MAIN IDEAS CRITICAL THINKING

1. Describe what a **growth factor** is and how it influences the cell cycle.
2. Explain how **cancer** cells differ from healthy cells.
3. **Contrast** How do **benign** and **malignant** tumors differ?
4. **Hypothesize** Suppose chromosomes in a skin cell are damaged by ultraviolet radiation. If the damaged genes do not affect cell cycle regulation, do you think the cell will become cancerous? Explain.

### Connecting CONCEPTS

5. **Cell Organelles** Some anticancer drugs prevent microtubules from forming spindle fibers. Why do you think these drugs might be effective treatments for cancer?

# 5.4

## Asexual Reproduction

**KEY CONCEPT** Many organisms reproduce by cell division.

### ▶ MAIN IDEAS

- Binary fission is similar in function to mitosis.
- Some eukaryotes reproduce through mitosis.

### VOCABULARY

**asexual reproduction**, p. 148

**binary fission**, p. 148



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**Connect** In this flashy world of ours, you may think that the humble bacterium would have little chance of finding a mate. No dazzling smile, no fancy hair products, no shiny car, and—if we are brutally honest—not even a brain. With all of these limitations, it may seem that our bacteria friends would be destined to die out. And yet, bacteria are found in abundance and live just about everywhere on Earth. How can there be so many bacteria?

### ▶ MAIN IDEA

## Binary fission is similar in function to mitosis.

Reproduction is a process that makes new organisms from one or more parent organisms. It happens in two ways—sexually and asexually. Sexual reproduction involves the joining of two specialized cells called gametes (eggs and sperm cells), one from each of two parents. The offspring that result are genetically unique; they have a mixture of genes from both parents. In contrast, **asexual reproduction** is the creation of offspring from a single parent and does not involve the joining of gametes. The offspring that result are, for the most part, genetically identical to each other and to the single parent.

### Binary Fission and Mitosis

Most prokaryotes reproduce through binary fission. **Binary fission** (BY-nuh-ree FIIHSH-uhn) is the asexual reproduction of a single-celled organism by division into two roughly equal parts. Binary fission and mitosis have similar results. That is, both processes form two daughter cells that are genetically identical to the parent cell. However, the actual processes are different in several important ways.

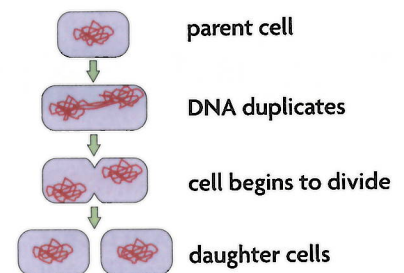
As you already learned, prokaryotes such as bacteria do not have nuclei. And although they do have DNA, they have much less of it than do most eukaryotes. Also, most of a bacterium's DNA is in the form of one circular chromosome, and bacteria have no spindle fibers.

### Connecting CONCEPTS

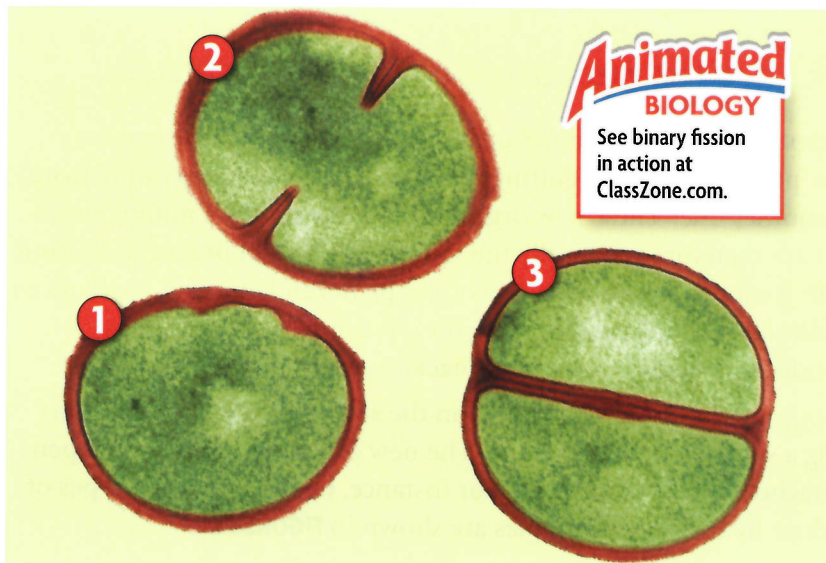
**Cell Structure** Recall from Chapter 3 that many scientists hypothesize that mitochondria and chloroplasts were originally free-living prokaryotes. One piece of evidence that supports this hypothesis is the fact that these two organelles replicate much as bacteria do, through fission.

### VISUAL VOCAB

**Binary fission** is the asexual reproduction of a single-celled organism by division into two roughly equal parts.







**FIGURE 5.13** Binary fission is shown in this micrograph of three individual bacteria, each at a different stage of binary fission. First, a cell elongates (1), and the DNA is replicated. Next, the cell membrane pinches inward (2). Finally, the membrane meets, and a new cell wall is laid down, forming two separate cells (3). (colored TEM; magnification 60,000 $\times$ )

Binary fission, shown in **FIGURE 5.13**, starts when the bacterial chromosome is copied. The two chromosomes are both attached to the cell membrane. As the cell grows and gets longer, the chromosomes move away from each other. When the cell is about twice its original size, it undergoes cytokinesis. The membrane pinches inward, and a new cell wall is laid down between the two chromosomes, which completes the separation into two daughter cells.

### Advantages and Disadvantages of Asexual Reproduction

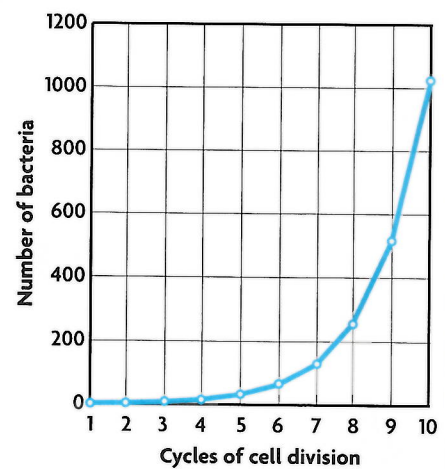
Very often, whether something is helpful or harmful depends on the situation. In favorable environments that do not change much, asexual reproduction can be more efficient than sexual reproduction. Recall that asexual reproduction results in genetically identical offspring. If they are well suited to the environment, genetic variation could be more harmful than helpful. In other words, if it ain't broke, don't fix it.

However, asexual reproduction may be a disadvantage in changing conditions. Genetically identical offspring will respond to the environment in the same way. If population members lack traits that enable them to reproduce, the entire population could die off. In contrast, sexual reproduction increases genetic diversity, which raises the chance that at least a few individuals will survive or even thrive in changing conditions.

Keep in mind, however, that the act of asexual reproduction itself is not more efficient; rather, the associated costs of sexual reproduction are greater. For example, all asexually reproducing organisms can potentially reproduce. Suppose two organisms each have ten offspring. If one organism reproduces asexually, all ten offspring can have offspring of their own. If the other organism reproduces sexually, having five females and five males, only the five females can bear offspring. In addition, sexually reproducing organisms must attract a mate. This effort involves not only the time and energy needed to find a mate but also many structures, signals, and behaviors that have evolved to attract mates. Organisms that reproduce asexually do not have these costs.

**Summarize** How is asexual reproduction an advantage in some conditions?

**FIGURE 5.14 BACTERIA GROWTH**



One bacterium can result in a total of 1024 cells after only 10 rounds of cell division.

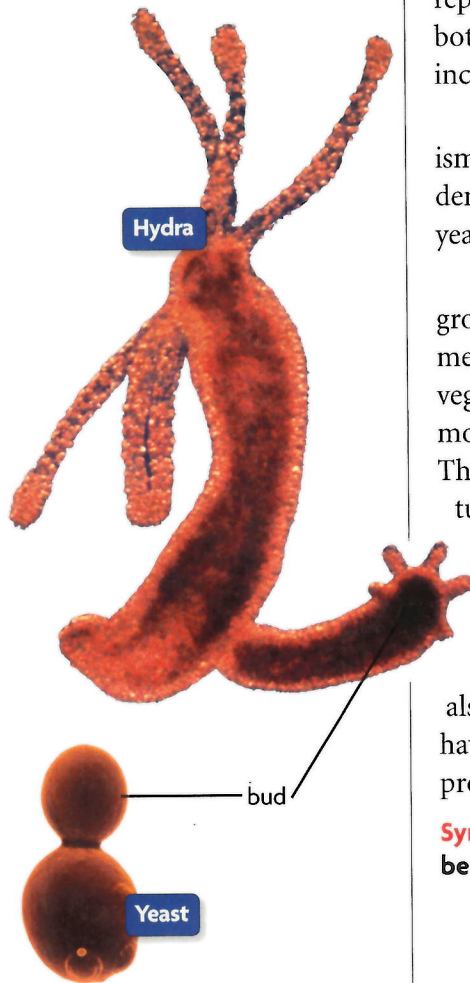
### Connecting CONCEPTS

**Evolution** As you will learn in **Chapter 18**, the misuse of antibiotics has resulted in multidrug-resistant bacteria. The bacteria not killed by antibiotics can reproduce quickly, passing the genes for antibiotic resistance on to their offspring.

## ▶ MAIN IDEA

# Some eukaryotes reproduce through mitosis.

**FIGURE 5.15** Yeast and hydras can reproduce by budding. (hydra: LM, magnification 12×; yeast: colored SEM, magnification 3,200×)



Some eukaryotes also reproduce asexually, through mitosis. Have you ever grown a new plant from a stem cutting? Or seen a new sea star growing from the arm of another one? These new organisms are the result of mitotic reproduction and are therefore genetically the same as the parent organism. Mitotic reproduction is especially common in simpler plants and animals. It occurs in both multicellular and unicellular eukaryotes. It can take several forms, including budding, fragmentation, and vegetative reproduction.

In budding, a small projection grows on the surface of the parent organism, forming a separate new individual. The new organism may live independently or attached as part of a colony. For instance, hydras and some types of yeast reproduce by budding. Examples are shown in **FIGURE 5.15**.

In fragmentation, a parent organism splits into pieces, each of which can grow into a new organism. Flatworms and sea stars both reproduce by fragmentation. Many plants, including strawberries and potatoes, reproduce via vegetative reproduction. In general, vegetative reproduction involves the modification of a stem or underground structures of the parent organism. The offspring often stay connected to the original organism, through structures called runners, for example.

Many organisms can reproduce both asexually and sexually. The form of reproduction may depend on the current conditions. The sea anemone can reproduce in many ways. It can reproduce asexually by dividing in half, by breaking off small pieces from its base, or by budding. It can also reproduce sexually by making eggs and sperm. Some species of anemone have males and females. In other anemone species, the same organism can produce both eggs and sperm cells.

**Synthesize** How might the asexual reproduction of genetically identical plants be useful to humans? How could it prove harmful to our food supply?

## 5.4 ASSESSMENT



### REVIEWING ▶ MAIN IDEAS

1. Explain how mitosis differs from **binary fission**.
2. Briefly explain why cutting a flatworm into pieces would not kill it.

### CRITICAL THINKING

3. **Infer** How does an organism benefit by being able to reproduce both sexually and asexually?
4. **Apply** Yeasts are growing in two dishes. You treat one dish with a chemical that blocks DNA replication but forget to label it. How can you identify the treated dish?

### Connecting CONCEPTS

5. **Ecology** Two populations live in the same habitat and compete for food. The first group is larger and uses **asexual reproduction**; the second reproduces sexually. What could happen to cause the second group to outnumber the first?

# 5.5

## Multicellular Life

**KEY CONCEPT** Cells work together to carry out complex functions.

### ▶ MAIN IDEAS

- Multicellular organisms depend on interactions among different cell types.
- Specialized cells perform specific functions.
- Stem cells can develop into different cell types.

### VOCABULARY

**tissue**, p. 151

**organ**, p. 151

**organ system**, p. 151

**cell differentiation**, p. 152

**stem cell**, p. 153

**Review**  
homeostasis



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**Connect** Each of us enters this world as a screaming infant. At first, the ability to eat solid foods or take a step draws forth great praise. These general skills rapidly lose their wonder, however, and by the time you reach the age of 18, everyone wants to know what you plan to do with yourself. Will you build houses or design clothing or treat patients? What will your specialty be? Cells, too, undergo specialization to carry out the complex functions required by the body.

### ▶ MAIN IDEA

## Multicellular organisms depend on interactions among different cell types.

Within multicellular organisms, cells communicate and work together in groups that form increasingly larger, more complex structures. This arrangement progresses from cells to tissues to organs to organ systems, as shown in **FIGURE 5.16**. **Tissues** are groups of cells that work together to perform a similar function. Groups of tissues that work together to perform a specific function or related functions are called **organs**. For instance, plants have photosynthetic tissues made of chlorophyll-containing cells. Conductive tissues transport sugars, water, and minerals to and from other parts of the plant. Protective tissues help prevent water loss. Together, these and other tissues form a leaf, the plant's food-producing organ.

Organs that carry out similar functions are further grouped into **organ systems**. In plants, the shoot system is above the ground. It includes stems that support the plant, leaves that capture radiant energy, and flowers that aid reproduction. Beneath the ground, the root system has different types of roots and root hairs that anchor the plant and absorb water and minerals.

As organ systems work together, they help an organism maintain homeostasis. For example, plants need to maintain a certain level of water within their cells, or they will wilt and die. They absorb water through their roots and expel it as water vapor through openings in their leaves called stomata. Stomata are controlled by special cells called guard cells, which close the stomata when a plant's water intake cannot keep up with its water loss.

**Apply** Suppose your family goes out of town and forgets to ask your neighbor to water the plants. Do you think the plants' stomata will be open or closed? Explain.

### Connecting CONCEPTS

**Homeostasis** As you learned in Chapter 1, homeostasis is the maintenance of a stable internal environment. Both an organism's physiology and its behavior help it achieve homeostasis.

## FIGURE 5.16 Levels of Organization

Cells work together in groups that form larger, specialized structures.

### CELL

Vessel elements are tube-shaped cells. (colored SEM; magnification 200×)



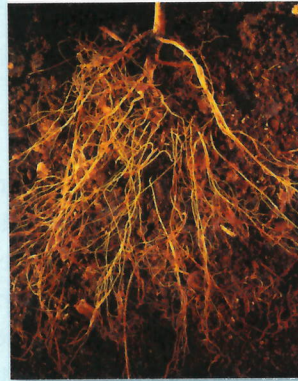
### TISSUE

Vessel elements, tracheids, and parenchyma cells form xylem. (colored SEM; magnification 240×)

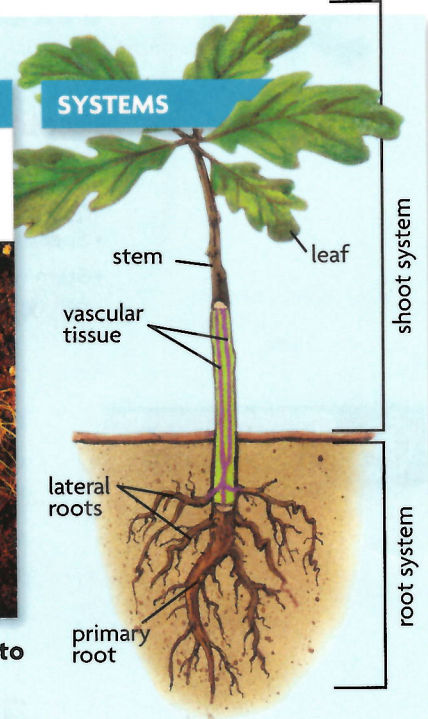


### ORGAN

Xylem and other tissues form roots that absorb water and nutrients.



### SYSTEMS



**Apply** How is the shape of this plant's roots suited to their function?

### MAIN IDEA

## Specialized cells perform specific functions.

### Connecting CONCEPTS

**Gametogenesis** As you will learn in Chapter 6, the egg is stocked with organelles and molecules necessary for an embryo to grow. Many of these molecules are not evenly distributed throughout the cell; they form gradients.

It is easy to see that a skin cell can divide to make a new skin cell, or that a single bacterium can generate another bacterium. But how does a complex organism like you develop? Your body began as a single fertilized egg. If the egg simply divided to make lots of identical cells, it would not form a baby. To form the intricate structures that make up your body and the bodies of countless organisms around you, cells must specialize.

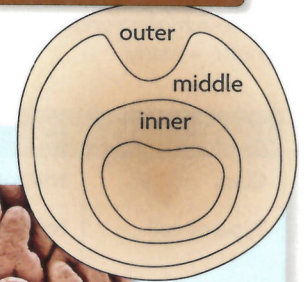
**Cell differentiation** is the process by which unspecialized cells develop into their mature forms and functions. While almost every cell in your body has a full set of DNA, each type of cell uses only the specific genes it needs to carry out its function. That is, a cell differentiates among the genes and uses only certain ones. You can think of your DNA as a cookbook. When you want to make a specific dish, you select that recipe and carry out its instructions. If you need to make a dessert, you might bake turtle brownies. If you need to make a main course, you might roast apple-stuffed pork chops or fix a hearty lentil stew. The dishes are very different, but they all come from the same cookbook.

A cell's location within the embryo helps determine how it will differentiate. In plant cells, the first division of a fertilized egg is unequal, or asymmetric, and produces two cells—the apical cell and the basal cell. The apical cell forms most of the embryo, including the growth point for stems and leaves. The major role of the basal cell is to provide nutrients to the embryo; it also creates the growth point for the roots. Plant cells cannot easily migrate because of the cell wall, but they adapt to changing conditions and continue to develop throughout their lifetime. As the plant grows, new cells continue to

differentiate based on their location. For example, cells on the outer layer of a leaf may become epidermal cells that secrete a waxy substance that helps prevent water loss. Cells on the lower leaf surface may become guard cells that control the exchange of water, air, and carbon dioxide.

In animals, an egg undergoes many rapid divisions after it is fertilized. The resulting cells can migrate to a specific area, and the cells quickly begin to differentiate. The early animal embryo generally takes the shape of a hollow ball. As the embryo develops, part of the ball folds inward, forming an inner layer and creating an opening in the outer cell layer. A middle layer of cells then forms between the other two.

Animal embryo cross section



## FIGURE 5.17 Cell Differentiation

Cell differentiation in the developing animal embryo is based on location.



**Outer** Skin cells help prevent infection and dehydration. (colored SEM; magnification 500×)



**Middle** Bone cells form a hard matrix (shown) that supports and protects organs. (colored SEM; magnification 15×)



**Inner** Intestinal epithelia have a large surface area that increases absorption. (colored SEM; magnification 25×)

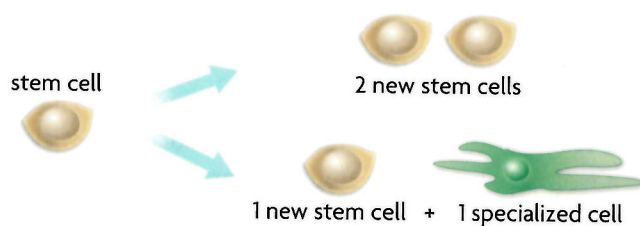
As shown in **FIGURE 5.17**, in vertebrates, the outer cell layer differentiates to form the outer layer of skin and elements of the nervous system such as the brain and spinal cord. The middle cell layer forms bones, muscles, kidneys, and the inner layer of skin. The inner cell layer forms internal organs such as the pancreas, lungs, and digestive system lining.

**Analyze** Why is regulation of the differentiation process during the early stages of development so critical?

### MAIN IDEA

## Stem cells can develop into different cell types.

**Stem cells** are a unique type of body cell that have the ability to (1) divide and renew themselves for long periods of time, (2) remain undifferentiated in form, and (3) develop into a variety of specialized cell types. When a stem cell divides, it forms either two stem cells or one stem cell and one specialized cell.



## VOCABULARY


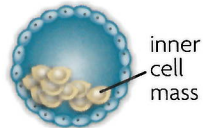

*Potent* comes from a Latin word meaning “to be able.” The addition of prefixes defines the level of power or ability.  
*toti-* = all  
*pluri-* = more, several  
*multi-* = many

## Stem Cell Classification

Stem cells can be categorized by their ability, or potential, to develop into the differentiated cell types of different tissues, as shown in **FIGURE 5.18**. In general, the more differentiated a stem cell already is, the fewer the types of cells it can form.

- Totipotent stem cells can grow into any other cell type. Only a fertilized egg and the cells produced by the first few divisions of an embryo are totipotent.
- Pluripotent stem cells can grow into any cell type except for totipotent stem cells.
- Multipotent stem cells can only grow into cells of a closely related cell family.

**FIGURE 5.18 STEM CELL CLASSIFICATION**

Class	totipotent	pluripotent	multipotent
Type of cell	fertilized egg 	embryonic stem cell 	adult stem cell (example from blood) 
Can give rise to	all cells	almost any cell	closely related cells
Example	new organism	neurons, skin, muscle, kidney, cartilage, bone, liver, pancreas	red blood cells, platelets, white blood cells

Stem cells are also classified by their origin, as either adult or embryonic. Adult stem cells have been studied for decades, but the ability to grow human embryonic stem cells was not developed until 1998. Since that time, embryonic stem cells have attracted great attention because of their potential to form almost any cell type. Both adult and embryonic stem cells offer unique advantages and challenges to researchers.

## Adult Stem Cells

Adult stem cells are partially undifferentiated cells located among the specialized cells of many organs and tissues. They are found all over the body, in the brain, liver, bone marrow, skeletal muscle, dental pulp, and even fat. These stem cells are also found in children and in umbilical cord blood, so the term *somatic stem cell* is more accurate although less frequently used.

A major advantage of adult stem cells is that they can be taken from a patient, grown in culture, and put back into the patient. Thus, the risk of transplant rejection by a patient’s immune system is very low. This method also avoids many ethical issues associated with using embryonic stem cells.

Adult stem cells currently pose many disadvantages as well. They are few in number, difficult to isolate, and sometimes tricky to grow. They may also contain more DNA abnormalities than do embryonic stem cells. For years, much evidence suggested that adult stem cells were multipotent. This would mean that a stem cell from fat would produce only fat cells, never muscle cells. Newer data suggest otherwise. Adult stem cells treated with the right combination of molecules may give rise to a completely different type of tissue. This process, called transdifferentiation, remains an active area of research.

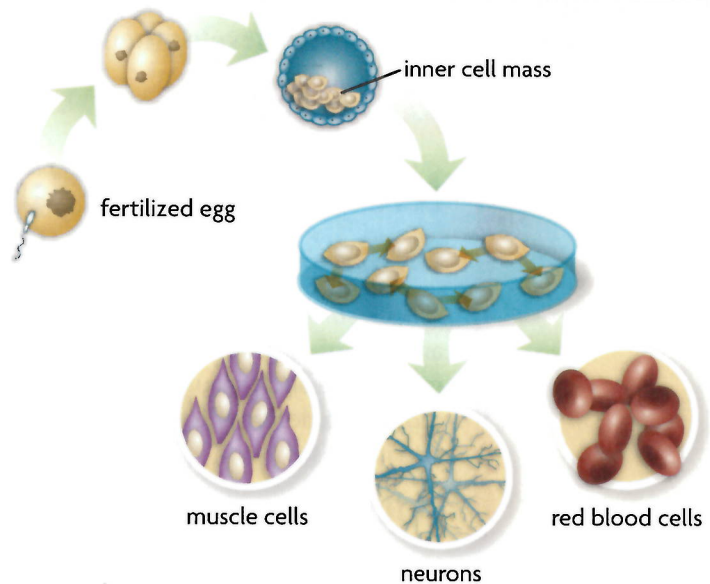
## Embryonic Stem Cells

Most embryonic stem cells come from donated embryos grown in a clinic. These embryos are the result of in vitro fertilization, a process by which eggs are fertilized outside a woman’s body. The stem cells are taken from a cluster of undifferentiated cells in the three-to-five-day-old embryo.

These cells, called the inner cell mass, do not have the characteristics of any specific cell type. Because they are pluripotent, they can form any of the 200 cell types of the body. They can also be grown indefinitely in culture. These qualities have given many people hope that many now devastating diseases will be treatable or even curable in the future.

Embryonic stem cells also have a downside. If these cells are used in treatment, a patient's body might reject them as foreign material. The stem cells could potentially grow unchecked in a patient's body and form a tumor. The use of embryonic stem cells also raises many ethical questions. The most common method of getting embryonic stem cells, **FIGURE 5.19**, currently involves destruction of the embryo, which some people consider ethically unacceptable.

**FIGURE 5.19 HARVESTING EMBRYONIC STEM CELLS**



First, an egg is fertilized by a sperm cell in a petri dish. The egg divides, forming an inner cell mass. These cells are then removed and grown with nutrients. Scientists try to control how the cells specialize by adding or removing certain molecules.

### Research and Treatment Hope

Stem cells have long been used to treat patients with leukemia and lymphoma, and they offer hope for treating many other diseases as well. For instance, some patients might be cured of diabetes if nonworking cells in the pancreas were replaced with healthy, growing cells. Similarly, damaged organs, such as the heart, might be strengthened by an injection of healthy cells. Research, such as the testing of new drugs, might also benefit. The current research system requires a lot of time and money. Many of the most innovative drugs have little chance of reaching the patient. Potentially, these new compounds could be tested on large numbers of specific cell types grown from stem cells.

**Compare and Contrast** List treatment benefits and risks of both types of stem cells.

## 5.5 ASSESSMENT



### REVIEWING MAIN IDEAS

1. How does communication between cells help maintain homeostasis?
2. Explain why **cell differentiation** is an important part of the development of a multicellular organism.
3. What are the defining characteristics of **stem cells**?

### CRITICAL THINKING

4. **Compare** Describe how **tissues**, **organs**, and **organ systems** are similar.
5. **Evaluate** Explain which factor you think is most important in deciding whether stem-cell research should be legal and government-funded.

### Connecting CONCEPTS

6. **Animal Behavior** Choose an animal and give an example of how its behavior reflects its need to maintain homeostasis.

Use these inquiry-based labs and online activities to deepen your understanding of cell growth and development.

## INVESTIGATION

### Modeling Cell Surface Area-to-Volume Ratio

A cell's surface area-to-volume ratio affects the amount of material that can diffuse across the membrane and throughout the cell. You will make cell models to determine how this ratio changes as cell size increases.

**SKILLS** Modeling, Inferring

**PROBLEM** Which cell has the greatest surface area-to-volume ratio?

#### PROCEDURE

1. Make three model cells by using the knife to cut three cubes from the phenolphthalein agar. Cell A should be 3 cm on each side, cell B should be 2 cm on each side, and cell C should be 1 cm on each side. Use the ruler to make exact measurements.
2. Calculate the area of one side of each cell. Calculate the total surface area of each cell. Record your data in Table 1. (**Hint:** Multiply the area of one side by the number of sides.)
3. Calculate the volume of each cell. Record your data in the table. (**Hint:** Multiply the length by the width by the height of the cube.)
4. Calculate the ratio of surface area to volume for each cell. For example, for cell A, the ratio would be  $54 \text{ cm}^2 : 27 \text{ cm}^3 = 2:1 = 2$ . Record your data.
5. Put the model cells in the beaker. Carefully cover them with sodium hydroxide solution, which turns the agar pink. Soak the cells in solution for four minutes. Use a spoon to turn the cells repeatedly throughout that time.
6. Remove the cells from solution and dry them on the paper towel.
7. Use the knife to cut each cube in half. Measure the distance from the edge of the cell to the inner edge of the pink line. This shows how far the sodium hydroxide diffused.

#### MATERIALS

- plastic knife
- phenolphthalein agar
- metric ruler
- 250-mL beaker
- 100-mL graduated cylinder
- 100 mL sodium hydroxide solution
- timer
- plastic spoon
- paper towel



TABLE 1. CALCULATIONS OF CELL SIZE

Cell	Area of One Side (cm <sup>2</sup> )	Total Surface Area (cm <sup>2</sup> )	Volume of Cell (cm <sup>3</sup> )	Surface Area-to-Volume Ratio
A				
B				
C				

#### ANALYZE AND CONCLUDE

1. **Analyze** How does the surface area-to-volume ratio change as cell size increases? How might this affect the diffusion of materials throughout a cell?
2. **Apply** Identify which cell turned pink in the greatest proportion, and explain how this relates to cell size.
3. **Apply** How does a cell's surface area-to-volume ratio affect its ability to stay alive?