

# 10.1

# Cell Growth, Division, and Reproduction

## Key Questions

**Key** What are some of the difficulties a cell faces as it increases in size?

**Key** How do asexual and sexual reproduction compare?

## Vocabulary

cell division  
asexual reproduction  
sexual reproduction

## Taking Notes

**Outline** As you read, create an outline about cell growth, division, and reproduction. As you read, fill in key phrases or sentences about each heading.

**THINK ABOUT IT** 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 of them? 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

**Key** What are some of the difficulties a cell faces as it increases in size?

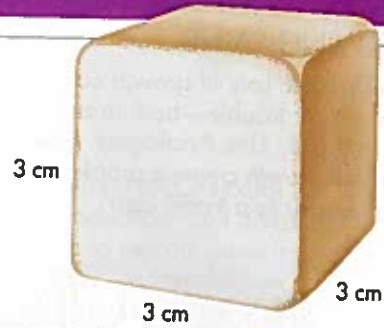
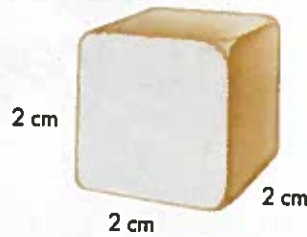
Nearly all cells can grow by increasing in size, but eventually, most cells divide after growing to a certain point. There are two main reasons why cells divide rather than continuing to grow. **Key** The larger a cell becomes, the more demands the cell places on its DNA. In addition, a larger cell is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

**Information “Overload”** 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 DNA does not. If a cell were to grow too large, an “information crisis” would occur.

To get a better sense of information overload, compare a cell to a growing town. Suppose a small town has a library with a few thousand books. As more people move in, more people will borrow books. Sometimes, people may have to wait to borrow popular books. Similarly, a larger cell would make greater demands on its genetic “library.” After a while, the DNA would no longer be able to serve the needs of the growing cell—it might be time to build a new library.

**Exchanging Materials** There is another critical reason why cell size is limited. Food, oxygen, and water enter a cell through its cell membrane. Waste products leave a 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 waste products are produced depends on the cell’s volume. Understanding the relationship between a cell’s surface area and its volume is the key to understanding why cells must divide rather than continue to grow.

## Ratio of Surface Area to Volume in Cells

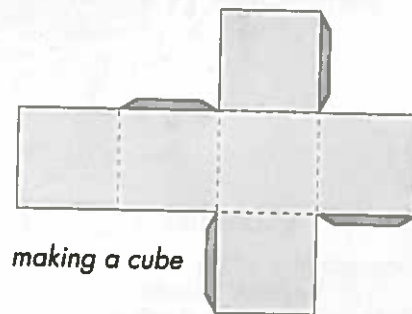


|  |   |   |  |
|--|---|---|--|
| Surface Area<br>(length x width) x 6 sides | $1\text{ cm} \times 1\text{ cm} \times 6 = 6\text{ cm}^2$           | $2\text{ cm} \times 2\text{ cm} \times 6 = 24\text{ cm}^2$          | $3\text{ cm} \times 3\text{ cm} \times 6 = 54\text{ cm}^2$           |
| Volume<br>(length x width x height)        | $1\text{ cm} \times 1\text{ cm} \times 1\text{ cm} = 1\text{ cm}^3$ | $2\text{ cm} \times 2\text{ cm} \times 2\text{ cm} = 8\text{ cm}^3$ | $3\text{ cm} \times 3\text{ cm} \times 3\text{ cm} = 27\text{ cm}^3$ |
| Ratio of Surface Area to Volume            | $6 / 1 = 6 : 1$   | $24 / 8 = 3 : 1$  | $54 / 27 = 2 : 1$  |

► **Ratio of Surface Area to Volume** Imagine a cell that is shaped like a cube, like those shown in **Figure 10–1**. 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 2 cm, and the ratio becomes 24/8 or 3 : 1. What if the length triples? The ratio of surface area to volume becomes 54/27 or 2 : 1. Notice that the surface area is not increasing as fast as the volume increases. For a growing cell, a decrease in the relative amount of cell membrane available creates serious problems.

**FIGURE 10–1 Ratio of Surface Area to Volume** As the length of the sides increases, the volume increases more than the surface area. **Interpret Tables** What are the ratios comparing?



## Quick Lab

OPEN-ENDED INQUIRY

### Modeling the Relationship Between Surface Area and Volume

- 1 Use drawing or grid paper to make patterns for a 6-cm cube, a 5-cm cube, a 4-cm cube, and a 3-cm cube.
- 2 Cut out your patterns and fold them. Then use the tabs to tape or glue the sides together. Don't tape down the top side.
- 3 Construct a data table to compare the volume, the surface area, and the ratio of surface area to volume of each cube.

- 4 Use your data to calculate the number of 3-cm cubes that would fit in the same volume as the 6-cm cube. Also calculate the total surface area for the smaller cubes. **MATH**

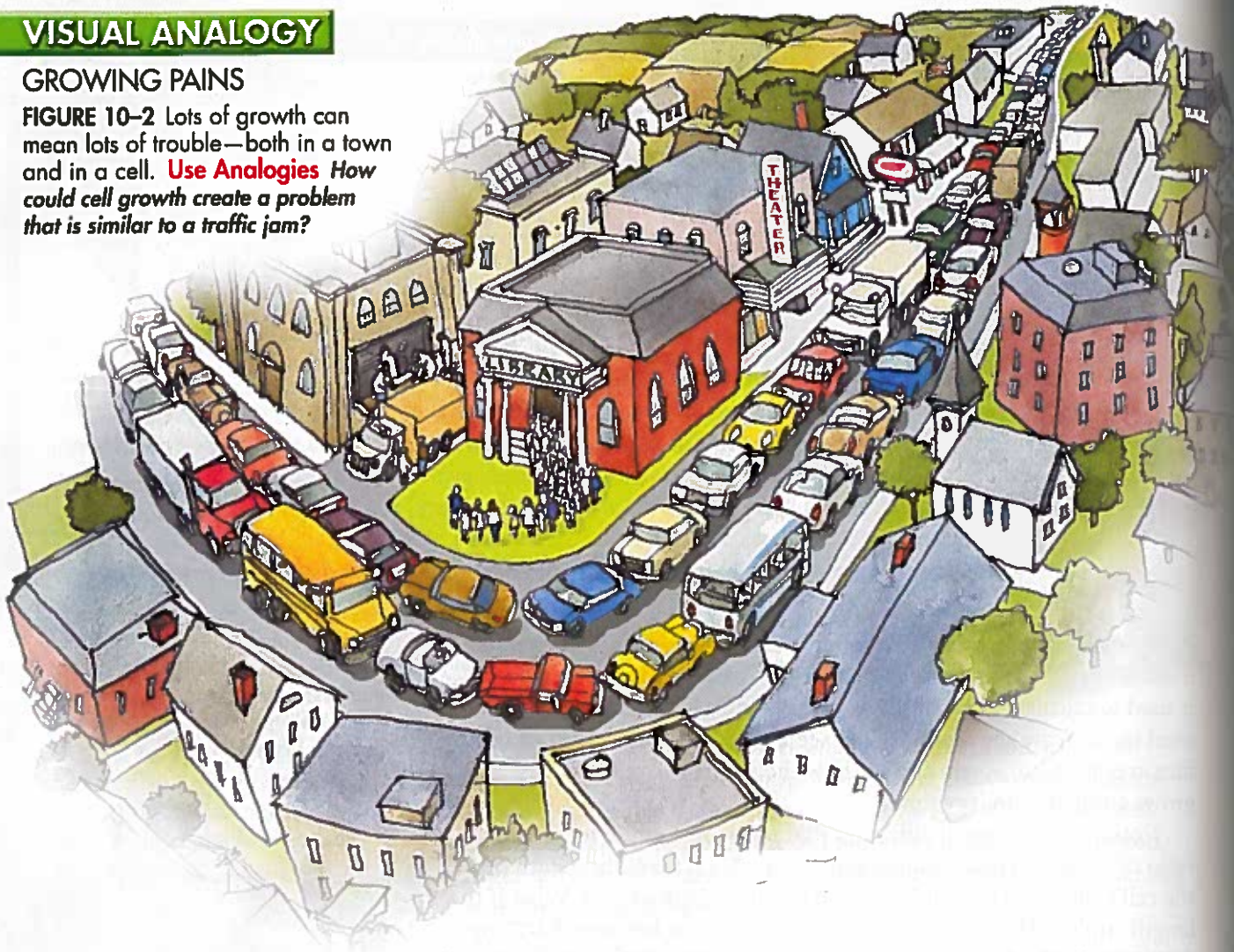
#### Analyze and Conclude

1. **Review** Describe the function of a cell membrane and its relationship to what happens inside a cell?
2. **Apply Concepts** How does the surface area change when a large cell divides into smaller cells that have the same total volume?

## VISUAL ANALOGY

### GROWING PAINS

**FIGURE 10-2** 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?



► **Traffic Problems** To use the town analogy again, suppose the town has just a two-lane main street leading to the center of town. As the town grows, more and more traffic clogs the main street. It becomes increasingly difficult to move goods in and out.

A cell that continues to grow would experience similar problems. If a cell got too large, it would be more difficult to get sufficient amounts of oxygen and nutrients in and waste products out. This is another reason why cells do not continue to grow larger even if the organism does.

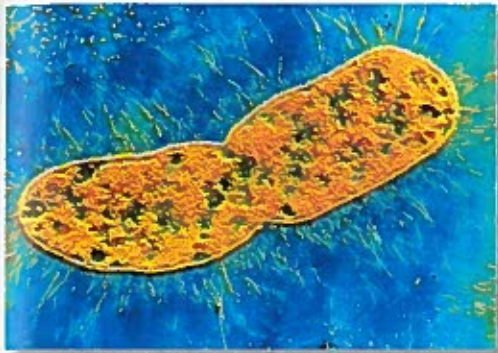
**Division of the Cell** Before it becomes too large, a growing cell divides, forming two “daughter” cells. The process by which a cell divides into two new daughter cells is called **cell division**.

Before cell division occurs, the cell replicates, or copies all of its DNA. This replication of DNA 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. Cell division results in an increase in the ratio of surface area to volume for each daughter cell. This allows for the efficient exchange of materials within a cell.

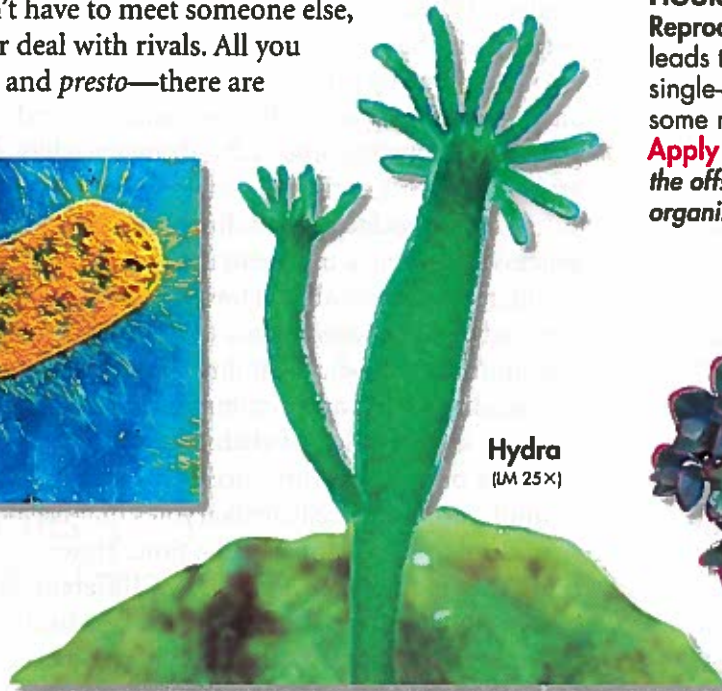
# Cell Division and Reproduction

## How do asexual and sexual reproduction compare?

Reproduction, the formation of new individuals, is one of the most important characteristics of living things. For an organism composed of just one cell, cell division 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!

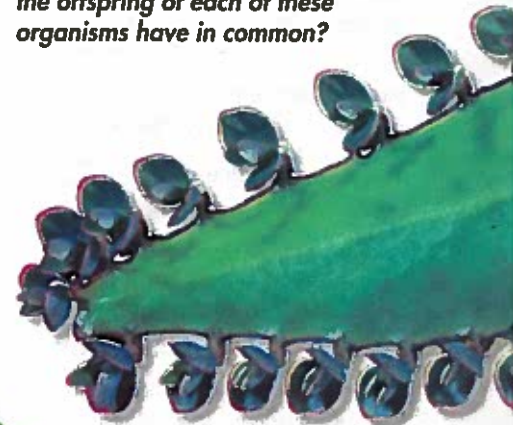


**Bacterium**  
(TEM 32,800×)



**Hydra**  
(LM 25×)

**FIGURE 10-3 Asexual Reproduction** Cell division leads to reproduction in single-celled organisms and some multicellular organisms. **Apply Concepts** What do the offspring of each of these organisms have in common?



**Kalanchoe**

**Asexual Reproduction** For many single-celled organisms, such as the bacterium in Figure 10-3, cell division is the 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. 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, where cells separate to form a new individual, **sexual reproduction** involves the fusion of two cells. In sexual reproduction, offspring are produced by the fusion of special 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, and so do many single-celled organisms. You will learn more about the form of cell division that produces reproductive cells in Chapter 11.

## BUILD Vocabulary

**PREFIXES** The prefix *a-* in *asexual* means “without.” **Asexual reproduction** is reproduction without the fusion of reproductive cells.



**In Your Notebook** Use a Venn diagram to compare asexual and sexual reproduction.

## MYSTERY CLUE

As its wound heals, the salamander's body cells are dividing to repair the damage. In what way is this type of cell division similar to asexual reproduction?



**Comparing Asexual and Sexual Reproduction** You can see that each type of reproduction has its advantages and disadvantages when you look at each one as a strategy for survival. Species survive by reproducing. The better suited a species is to its environment, the greater its chance of survival.

For single-celled organisms, asexual reproduction is a survival strategy. When conditions are right, the faster they reproduce, the better their chance of survival over other organisms using the same resources. Having offspring that are genetically identical is also an advantage as long as conditions remain favorable. However, a lack of genetic diversity becomes a disadvantage when conditions change in ways that do not fit the characteristics of an organism.

Sexual reproduction is a different type of survival strategy. The process of finding a mate and the growth and development of offspring require more time. However, this can be an advantage for species that live in environments where seasonal changes affect weather conditions and food availability. Sexual reproduction also provides genetic diversity. If an environment changes, some offspring may have the right combination of characteristics needed to survive.

Some organisms reproduce both sexually and asexually. Yeasts, for example, are single-celled eukaryotes that use both strategies. They reproduce asexually most of the time. However, under certain conditions, they enter a sexual phase. 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.

## 10.1 Assessment

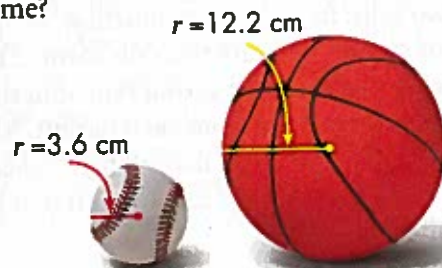
### Review Key Concepts

- Review** Identify two reasons why a cell's growth is limited.
  - Explain** As a cell's size increases, what happens to the ratio of its surface area to its volume?
  - Applying Concepts** Why is a cell's surface area-to-volume ratio important?
- Review** What is asexual reproduction? What is sexual reproduction?
  - Explain** What types of organisms reproduce sexually?
  - Summarize** What are the advantages and disadvantages of both asexual and sexual reproduction?

### VISUAL THINKING

### MATH

- The formula for finding the surface area of a sphere, such as a baseball or a basketball, is  $A = 4\pi r^2$ , where  $r$  is the radius. The formula for finding the volume of a sphere is  $V = 4/3\pi r^3$ .
  - Calculate** Calculate the surface area and the volume of the baseball and the basketball. Then, write the ratio of surface area to volume for each sphere.
  - Infer** If the baseball and basketball were cells, which would possess a larger ratio of area of cell membrane to cell volume?



# 10.2

# The Process of Cell Division

**THINK ABOUT IT** What role does cell division play in your life? You know from your own experience that living things grow, or increase in size, during particular stages of life or even throughout their lifetime. This growth clearly depends on the production of new cells through cell division. But what happens when you are finished growing? Does cell division simply stop? Think about what must happen when your body heals a cut or a broken bone. And finally, think about the everyday wear and tear on the cells of your skin, digestive system, and blood. Cell division has a role to play there, too.

## Chromosomes

**Key Question** What is the role of chromosomes in cell division?

What do you think 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, and 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**.

**Prokaryotic Chromosomes** Prokaryotes lack nuclei and many of the organelles found in eukaryotes. Their DNA molecules are found in the cytoplasm along with most of the other contents of the cell. Most prokaryotes contain a single, circular DNA chromosome that contains all, or nearly all, of the cell's genetic information.



Chromosome

**FIGURE 10-4 Prokaryotic Chromosome** In most prokaryotes, a single chromosome holds most of the organism's DNA.

## Key Questions

**Key Question 1** What is the role of chromosomes in cell division?

**Key Question 2** What are the main events of the cell cycle?

**Key Question 3** What events occur during each of the four phases of mitosis?

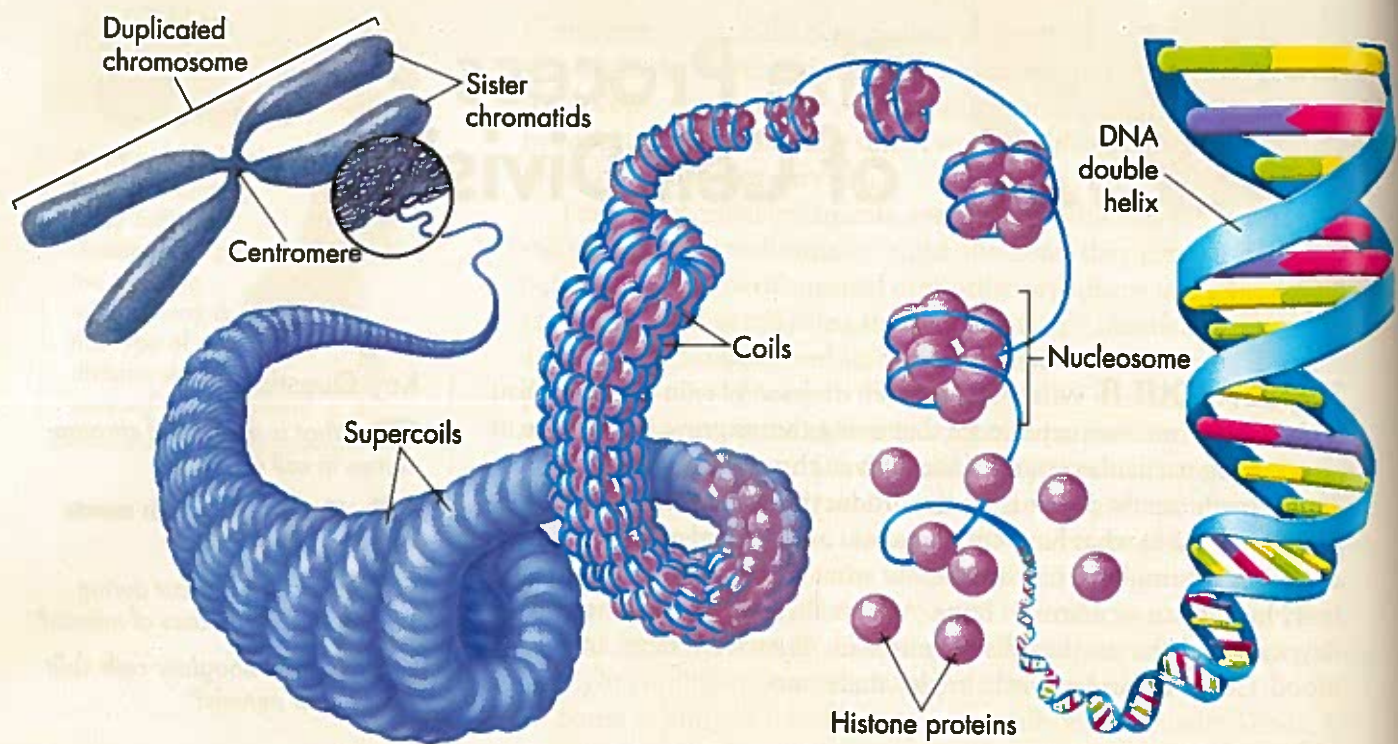
**Key Question 4** How do daughter cells split apart after mitosis?

## Vocabulary

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

## Taking Notes

**Two-Column Chart** As you read, create a two-column chart. In the left column, make notes about what is happening in each stage of the cell cycle. In the right column, describe what the process looks like or draw pictures.



**FIGURE 10-5 Eukaryotic Chromosome** As a eukaryotic cell prepares for division, each chromosome coils more and more tightly to form a compact structure. **Interpret Visuals** Which side of the diagram, left or right, shows the smallest structures, and which shows the largest?

**Eukaryotic Chromosomes** Eukaryotic cells generally have much more DNA than prokaryotes have and, therefore, contain multiple chromosomes. Fruit flies, for example, have 8 chromosomes per cell, human cells have 46, and carrot cells have 18. Eukaryotic chromosomes contain both DNA and protein, tightly associated to form a substance called **chromatin**. Chromatin consists of DNA tightly coiled around special proteins known as histones. 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.

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 make it possible to separate DNA precisely during cell division.**

**In Your Notebook** Write instructions to build a eukaryotic chromosome.

## The Cell Cycle

**🔑 What are the main events of the cell cycle?**

All 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 divides to form two daughter cells.** Each daughter cell then moves into a new cell cycle of activity, growth, and division.

**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 only 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.

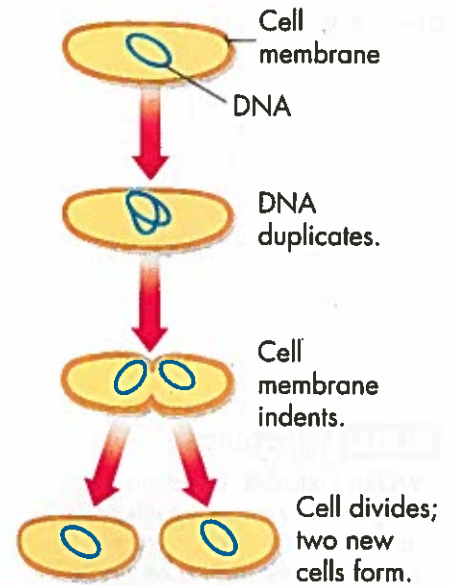
The process of cell division in prokaryotes is a form of asexual reproduction known as binary fission. Once the chromosome has been replicated, the two DNA molecules attach to different regions of the cell membrane. A network of fibers forms between them, stretching from one side of the cell to the other. The 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.

**The Eukaryotic Cell Cycle** In contrast to prokaryotes, much more is known about the eukaryotic cell cycle. As you can see in Figure 10-7, the eukaryotic cell cycle consists of four phases: G<sub>1</sub>, S, G<sub>2</sub>, and M. The length of each part of the cell cycle—and the length of the entire cell cycle—varies depending on the type of cell.

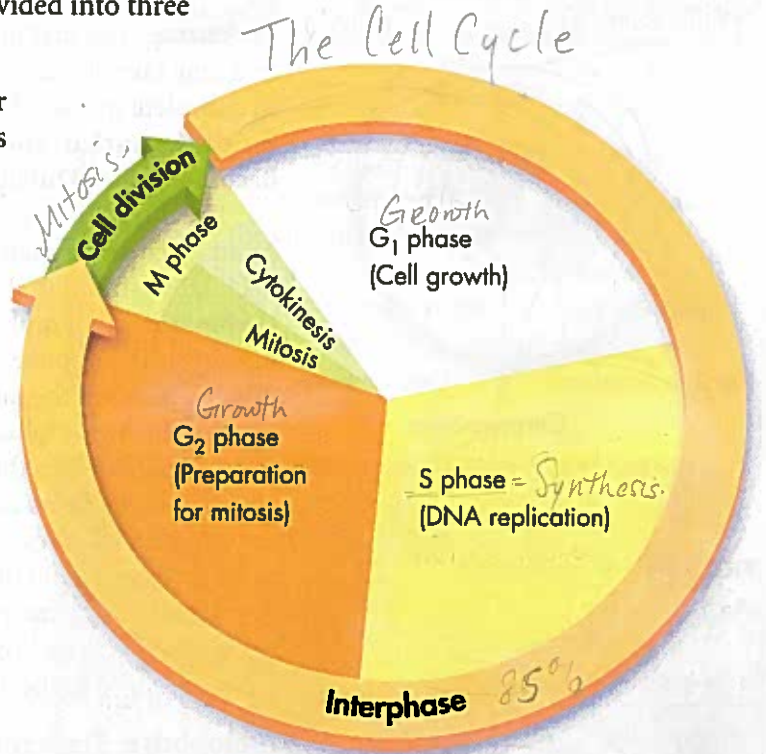
At one time, biologists described the life of a cell as one cell division after another separated by an “in-between” period of growth called **interphase**. We now appreciate that a great deal happens in the time between cell divisions. Interphase is divided into three parts: G<sub>1</sub>, S, and G<sub>2</sub>.

► **G<sub>1</sub> Phase: Cell Growth** Cells do most of their growing during the G<sub>1</sub> phase. In this phase, cells increase in size and synthesize new proteins and organelles. The G in G<sub>1</sub> and G<sub>2</sub> stands for “gap,” but the G<sub>1</sub> and G<sub>2</sub> phases are actually periods of intense growth and activity.

► **S Phase: DNA Replication** The G<sub>1</sub> phase is followed by the S phase. The S stands for “synthesis.” During the S phase, new DNA is synthesized when the chromosomes are replicated. The cell at the end of the S phase contains twice as much DNA as it did at the beginning.



**FIGURE 10-6 Binary Fission** Cell division in a single-celled organism produces two genetically identical organisms.



**FIGURE 10-7 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<sub>1</sub>, S, G<sub>2</sub>, and M. **Infer** During which phase or phases would you expect the DNA content of the cell to change?



## BUILD Vocabulary

**WORD ORIGINS** The prefix *cyto-* in **cytokinesis** refers to cells and derives from the Greek word *kytos*, meaning "a hollow vessel." *Cytoplasm* is another word that has the same root.

FIGURE 10-8 Prophase

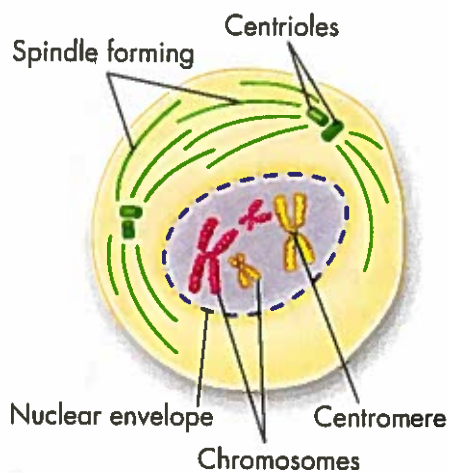
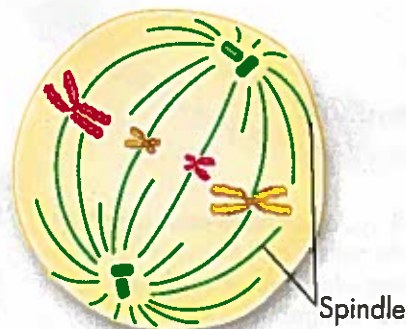


FIGURE 10-9 Metaphase



► **G<sub>2</sub> Phase: Preparing for Cell Division** When DNA replication is completed, the cell enters the G<sub>2</sub> phase. G<sub>2</sub> is usually the shortest of the three phases of interphase. During the G<sub>2</sub> phase, many of the organelles and molecules required for cell division are produced. When the events of the G<sub>2</sub> 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, division of the cell nucleus, is called **mitosis** (my TOH sis). The second stage, the division of the cytoplasm, is called **cytokinesis** (sy toh kih NEE sis). In many cells, the two stages may overlap, so that cytokinesis begins while mitosis is still taking place.

## Mitosis

🔑 **What events occur during each of the four phases of 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. Figure 10-8 through Figure 10-11 show mitosis in an animal cell.

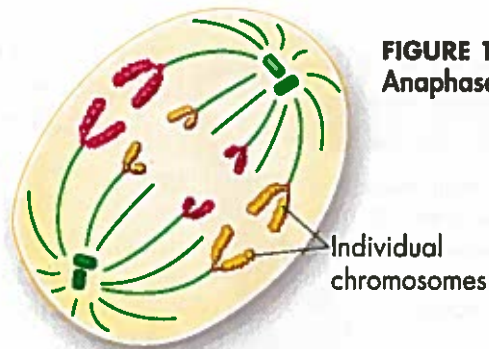
**Prophase** The first phase of mitosis, **prophase**, is usually the longest and may take as much as 50 to 60 percent of the total time required to complete mitosis. 🔑 **During prophase, the genetic material inside the nucleus condenses and the duplicated chromosomes become visible. Outside the nucleus, a spindle starts to form.**

The duplicated strands of the DNA molecule can be seen to be attached along their length at an area called the **centromere**. Each DNA strand in the duplicated chromosome is referred to as a **chromatid** (KROH muh tid), or sister chromatid. When the process of mitosis is complete, the chromatids will have separated and been divided between the new 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. Centrioles, as you may recall, are found only in animal cells. The centrioles, which were duplicated during interphase, start to move toward opposite ends, or poles, of the cell. As prophase ends, the chromosomes coil more tightly, the nucleolus disappears, and the nuclear envelope breaks down.

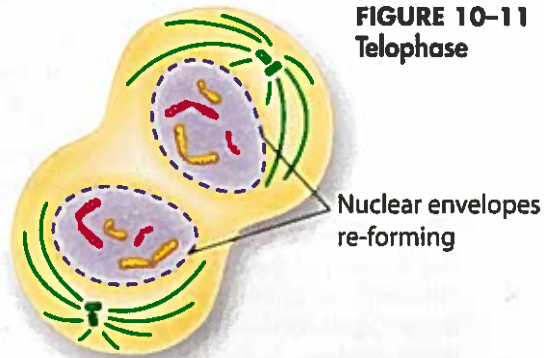
**Metaphase** The second phase of mitosis, **metaphase**, often lasts only a few minutes. 🔑 **During metaphase, the centromeres of the duplicated chromosomes line up across the center of the cell. Spindle fibers connect the centromere of each chromosome to the two poles of the spindle.**

**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 comes to an end when this movement stops and the chromosomes are completely separated into two groups.



**FIGURE 10-10**  
Anaphase

**Telophase** Following anaphase is **telophase**, the fourth and 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. The spindle begins to break apart, and a nucleolus becomes visible in each daughter nucleus. Mitosis is complete. However, the process of cell division is not yet complete.



**FIGURE 10-11**  
Telophase

**In Your Notebook** Create a chart that lists the important information about each phase of mitosis.

## Quick Lab

GUIDED INQUIRY

### Mitosis in Action

1. **Examine** a slide of a stained onion root tip under a microscope. Viewing the slide under low power, adjust the stage until you find the boxlike cells just above the root tip.
2. Switch the microscope to high power and locate cells that are in the process of dividing.
3. Find and sketch cells that are in each phase of mitosis. Label each sketch with the name of the appropriate phase.

### Analyze and Conclude

1. **Observe** In which phase of the cell cycle were most of the cells you observed? Why do you think this is?
2. **Draw Conclusions** What evidence did you observe that shows mitosis is a continuous process, not a series of separate events?

3. **Apply Concepts** Cells in the root divide many times as the root grows longer and thicker. With each cell division, the chromosomes are divided between two daughter cells, yet the number of chromosomes in each cell does not change. What processes ensure that the normal number of chromosomes is restored after each cell division?



[LM 820x]

## MYSTERY CLUE

How might the cell cycles of the cells surrounding the salamander's wound be affected?

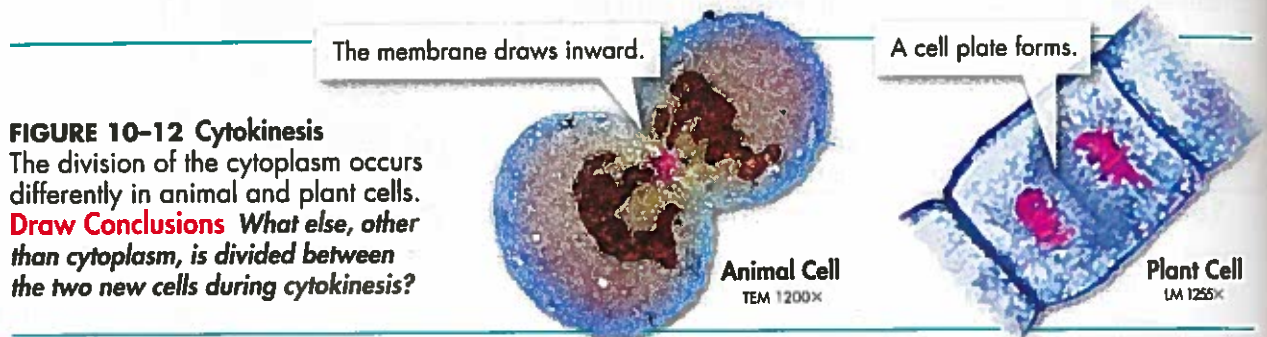


## Cytokinesis

**Key** How do daughter cells split apart after mitosis?

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 itself. Cytokinesis usually occurs at the same time as telophase. **Key** Cytokinesis completes the process of cell division—it splits one cell into two. The process of cytokinesis differs in animal and plant cells.

**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.



**FIGURE 10-12 Cytokinesis** The division of the cytoplasm occurs differently in animal and plant cells. **Draw Conclusions** What else, other than cytoplasm, is divided between the two new cells during cytokinesis?

**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.

## 10.2 Assessment

### Review Key Concepts **Key**

- a. Review** What are chromosomes?

**b. Compare and Contrast** How does the structure of chromosomes differ in prokaryotes and eukaryotes?
- a. Review** What is the cell cycle?

**b. Sequence** During which phase of the cell cycle are chromosomes replicated?
- a. Review** What happens during each of the four phases of mitosis? Write one or two sentences for each phase.

**b. Predict** What do you predict would happen if the spindle fibers were disrupted during metaphase?
- a. Review** What is cytokinesis and when does it occur?

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

### WRITE ABOUT SCIENCE

#### Summary

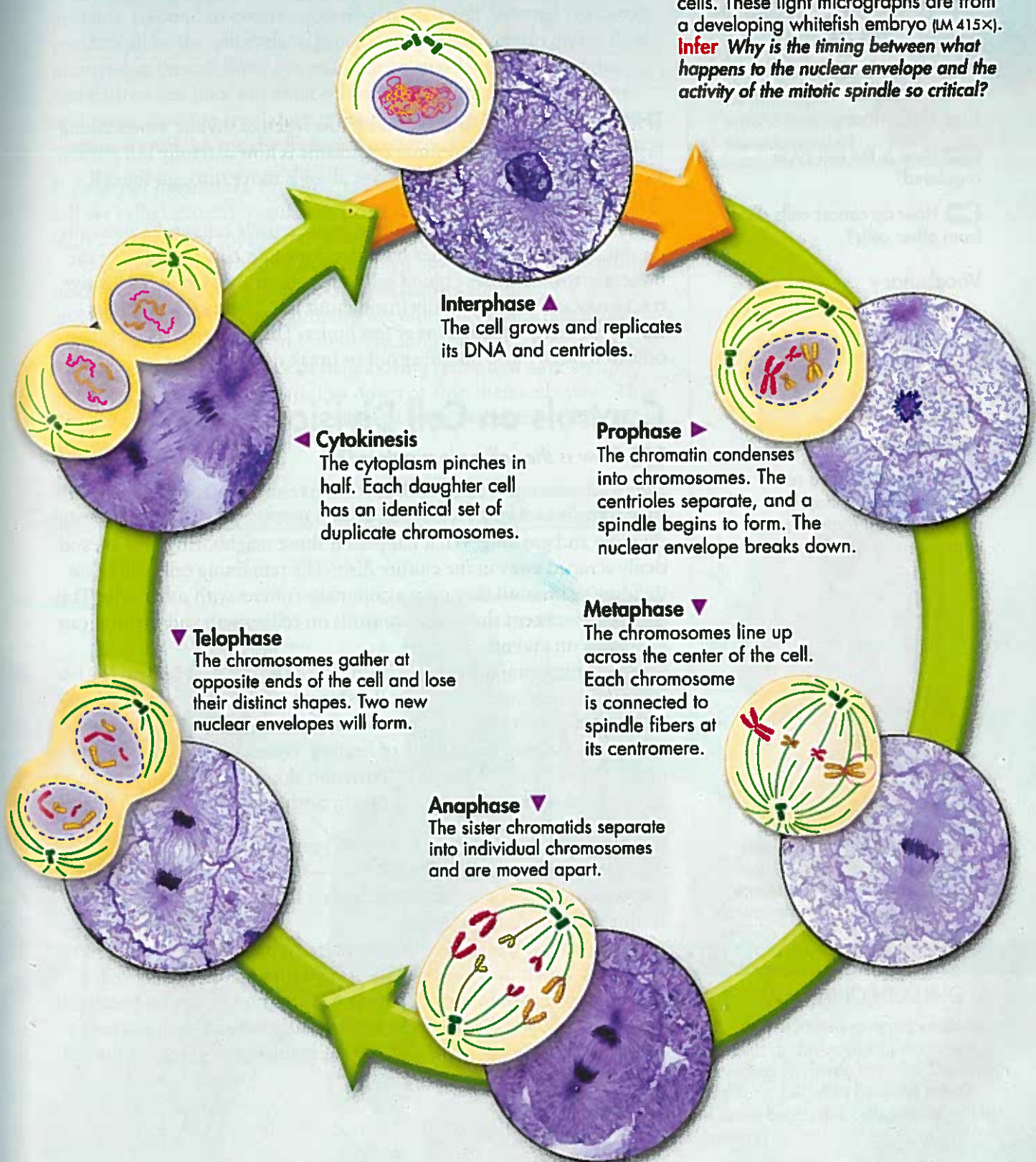
- Summarize what happens during interphase. Be sure to include all three parts of interphase. *Hint:* Include all of the main details in your summary.

## VISUAL SUMMARY

### MITOSIS

**FIGURE 10-13** The phases of mitosis shown here are typical of eukaryotic cells. These light micrographs are from a developing whitefish embryo (LM 415X).

**Infer** Why is the timing between what happens to the nuclear envelope and the activity of the mitotic spindle so critical?



# 10.3

## Regulating the Cell Cycle

### Key Questions

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

### Vocabulary

cyclin  
growth factor  
apoptosis  
cancer  
tumor

### Taking Notes

**Concept Map** As you read, create a concept map to organize the information in this lesson.

### BUILD Vocabulary

**ACADEMIC WORDS** The verb **regulate** means “to control or direct.” Therefore, a substance that regulates the cell cycle controls when the cell grows and divides.

**THINK ABOUT IT** How do cells know when to divide? One striking fact about cells in multicellular organisms is how carefully cell growth and cell division are controlled. Not all cells move through the cell cycle at the same rate.

In the human body, for example, most muscle cells and nerve cells do not divide at all once they have developed. In contrast, cells in the bone marrow that make blood cells and cells of the skin and digestive tract grow and divide rapidly throughout life. These cells may pass through a complete cycle every few hours. This process provides new cells to replace those that wear out or break down.

### Controls on Cell Division


How is the cell cycle regulated?

When scientists grow cells in the laboratory, most cells will divide until they come into contact with each other. Once they do, they usually stop dividing and growing. What happens if those neighboring cells are suddenly scraped away in 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 10–14**. 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 everything returns to normal.

**The Discovery of Cyclins** For many years, biologists searched for a signal that might regulate the cell cycle—something that would “tell” cells when it was time to divide, duplicate their chromosomes, or enter another phase of the cell cycle.


In the early 1980s, biologists discovered a protein in cells that were in mitosis. When they injected the 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.

**Regulatory Proteins** The discovery of cyclins was just the start. Scientists have since identified dozens of other proteins that also 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 proteins, internal regulatory proteins, respond to events occurring inside a cell. Internal regulatory proteins allow the cell cycle to proceed only when certain events have occurred in the cell itself. For example, several regulatory proteins make sure a cell does not enter mitosis until its chromosomes have replicated. Another regulatory protein prevents a cell from entering anaphase until the spindle fibers have attached to the chromosomes.

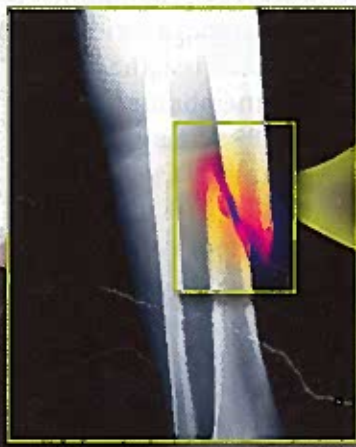
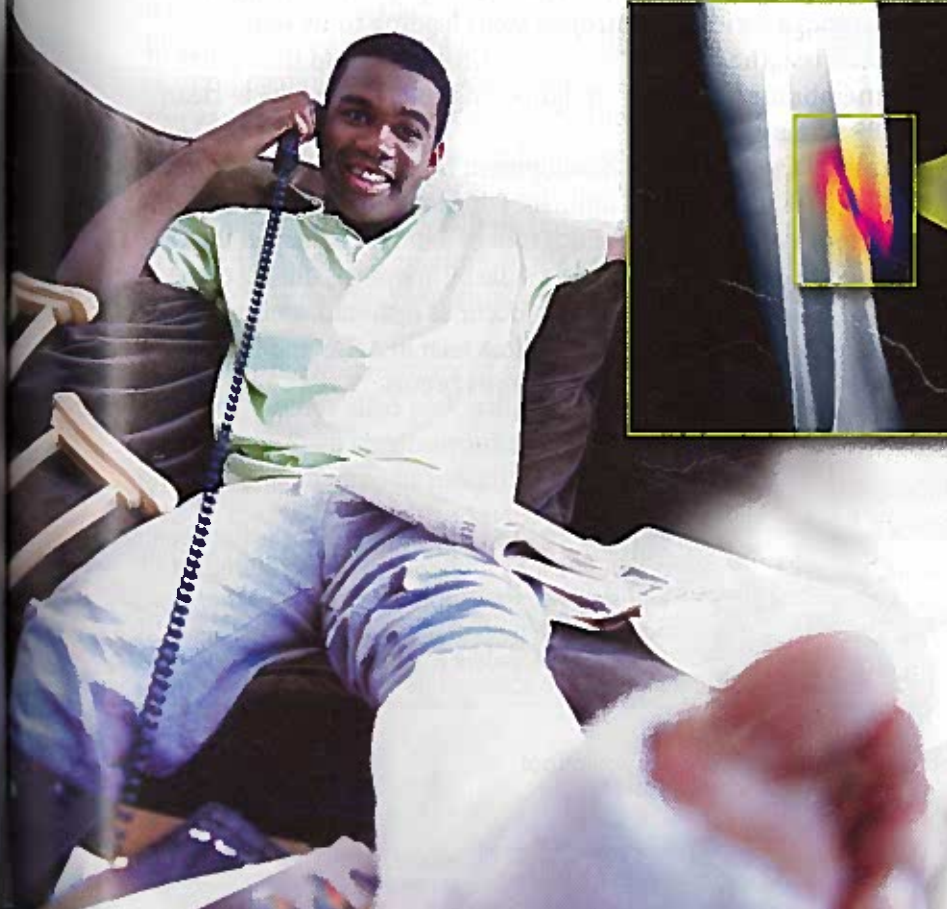
► **External Regulators** Proteins that respond to events outside the cell are called external regulatory proteins. External regulatory proteins direct cells to speed up or slow down the cell cycle.

One important group of external regulatory proteins is the group made up of the 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 an opposite effect. They cause cells to slow down or stop their cell cycles. This prevents excessive cell growth and keeps body tissues from disrupting one another.

 **In Your Notebook** Use a cause-and-effect diagram to describe how internal and external regulators work together to control the cell cycle.

## MYSTERY CLUE

How might regulatory proteins be involved in wound healing in the salamander?



New bone cells



## ZOOMING IN

### CELL GROWTH AND HEALING

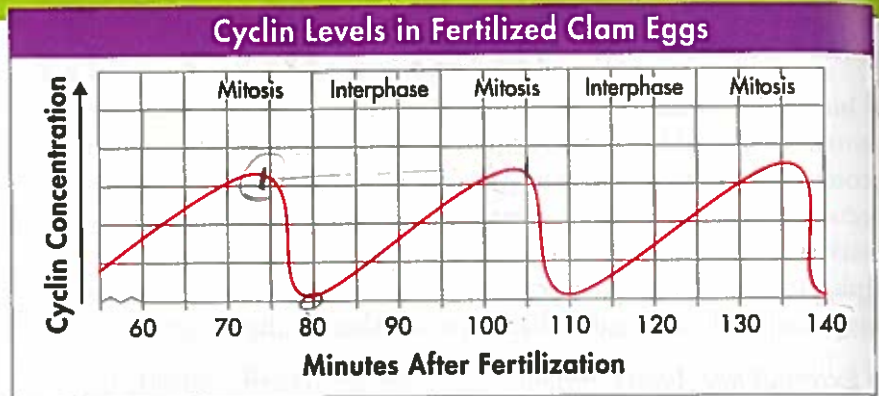
**FIGURE 10-14** When a person breaks a bone, cells at the edges of the injury are stimulated to divide rapidly. The new cells that form begin to heal the break. As the bone heals, the cells stop dividing and growing.

# Analyzing Data

## The Rise and Fall of Cyclins

Scientists measured cyclin levels in clam egg cells as the cells went through their first mitotic divisions after fertilization. The data are shown in the graph.

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



- 1. Interpret Graphs** How long does cyclin production last during a typical cell cycle in fertilized clam eggs?
- 2. Infer** During which part of the cell cycle does cyclin production begin? How quickly is cyclin destroyed?
- 3. Predict** Suppose that the regulators that control cyclin production are no longer produced. What are two possible outcomes?

**Apoptosis** Just as new cells are produced every day in a multicellular organism, many other cells die. Cells end their life cycle in one of two ways. 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 development by shaping the structure of tissues and organs in plants and animals. For example, look at the photos of a mouse foot in Figure 10–15. Each foot of a mouse is shaped the way it is partly because cells between the toes die by apoptosis during tissue development. When apoptosis does not occur as it should, 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.



**FIGURE 10–15 Apoptosis** The cells between a mouse’s toes undergo apoptosis during a late stage of development. **Predict** What is one way the pattern of apoptosis would differ in foot development for a duck?

# Cancer: Uncontrolled Cell Growth

## How do cancer cells differ from other cells?

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 cells divide uncontrollably.** Cancer cells form a mass of cells called a **tumor**. However, not all tumors are cancerous. Some tumors 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 in **Figure 10–16**, are malignant. Malignant tumors invade and destroy surrounding healthy tissue.

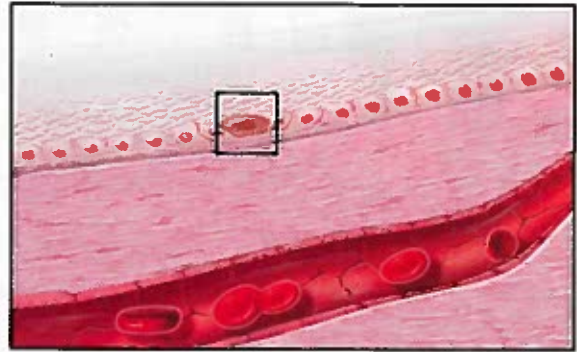
As the cancer cells spread, they absorb the nutrients needed by other cells, block nerve connections, and prevent the organs they invade from functioning properly. Soon, the delicate balances that exist in the body are disrupted, and life-threatening illness results.

**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, other defective genes, 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.

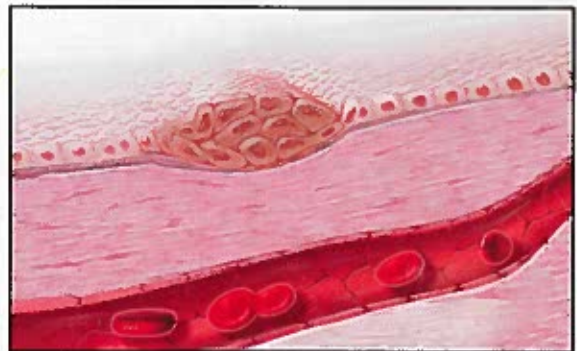
An astonishing number of cancer cells have a defect in a gene called p53, which normally halts the cell cycle until all chromosomes have been properly replicated. Damaged or defective p53 genes cause cells to lose the information needed to respond to signals that normally control their growth.

**In Your Notebook** Use a two-column chart to compare the controls that regulate normal cell growth to the lack of control seen in cancer cells.

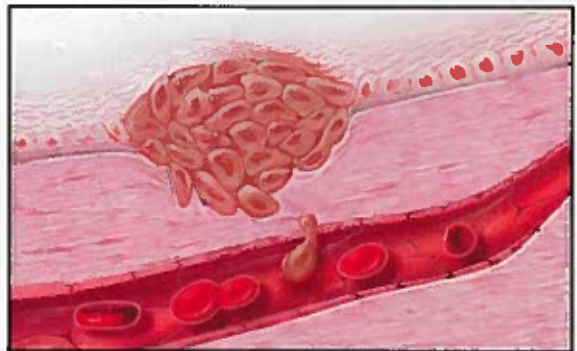
**FIGURE 10–16 Growth of Cancer Cells** Normal cells grow and divide in a carefully controlled fashion. Cells that are cancerous lose this control and continue to grow and divide, producing tumors.



1 A cell begins to divide abnormally.



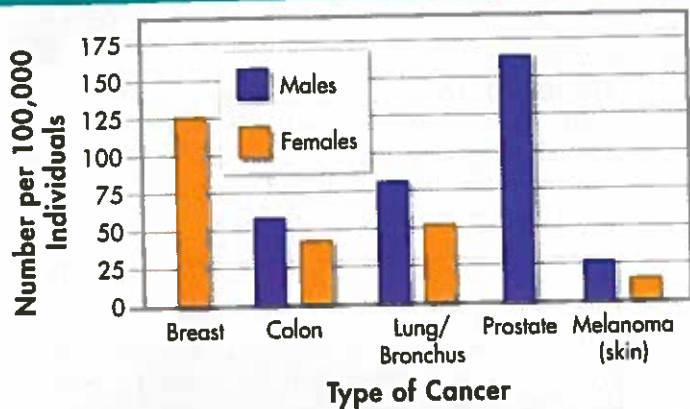
2 The cancer cells produce a tumor, which begins to displace normal cells and tissues.



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.



## Cancer Incidence in Males and Females (2000–2004)



**FIGURE 10-17 Cancer Incidence** Cancer can affect almost every organ in the body. **Interpret Graphs** How many cases of breast cancer were reported compared to prostate cancer for the time period shown?

**Treatments for Cancer** When a cancerous tumor is localized, it can often be removed by surgery. Skin cancer, the most common form 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.

Other forms of treatment make use of the fact that cancer cells grow rapidly and, therefore, need to copy their DNA more quickly than do most normal cells. This makes them especially vulnerable to damage from 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, and it is one of the reasons why scientists are so interested in gaining a better understanding of the role of cell cycle proteins in cancer. The goal of many researchers is 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 a much deeper understanding of the processes that control cell division.

## 10.3 Assessment

### Review Key Concepts

- Review** Name the two types of proteins that regulate the cell cycle. How do these proteins work?
  - Form a Hypothesis** Write a hypothesis about what you think would happen if cyclin were injected into a cell during mitosis. How could you test your hypothesis?
- Review** Why is cancer considered a disease of the cell cycle?
  - Compare and Contrast** How are the growth of a tumor and the repair of a scrape on your knee similar? How are they different?

### Apply the Big Idea

#### Growth, Development, and Reproduction

- Why do you think it is important that cells have a “control system” to regulate the timing of cell division?

# Technology & BIOLOGY

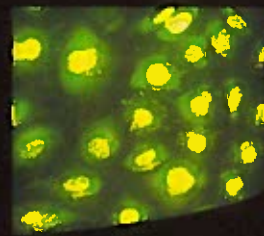


## Fluorescence Microscopy

Imagine being able to “see” proteins at work inside a cell, or to track proteins from where they are made to where they go. Scientists can now do all of these things, thanks to advances in fluorescence microscopy. One advance came from the discovery that crystal jellyfish, properly known as *Aequorea victoria*, produce a protein that glows. By fusing the gene for this protein to other genes, scientists can label different parts of the cell with fluorescence. Other advances include the development of additional highly specific fluorescent labels and the invention of powerful laser microscopes. As the images on this page show, the view is clearly amazing.

### WRITING

Suppose you are a cell biologist studying cell division and cancer. What might you use a fluorescence microscope to study? Describe your ideas in a paragraph.



### ▲ Viewing Labeled Specimens

In fluorescence microscopy, a specimen is labeled with a molecule that glows under a specific wavelength of light. Different fluorescent labels give off different colors. This way, biologists can easily see exactly where a protein is located within a cell or tissue.

### ▼ Normal Spindle

Different fluorescent labels enable biologists to track how spindle fibers form (green) and how proteins help distribute chromosomes evenly during mitosis (red).

### ▼ Abnormal Spindle

Cell cycle control has gone awry in this cell, causing an abnormal mitotic spindle to form.

# 10.4

## Cell Differentiation

### 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?

### Vocabulary

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

### Taking Notes

**Compare/Contrast Table** As you read, create a table comparing the ability of different cell types to differentiate.

**THINK ABOUT IT** The human body contains an estimated 100,000,000,000,000 (one hundred trillion) cells. That's a staggering number, but in one respect it's not quite as large as you might think. Why? Try to estimate how many times a single cell would have to divide through mitosis to produce that many cells. It may surprise you to learn that as few as 47 rounds of cell division can produce that many cells.

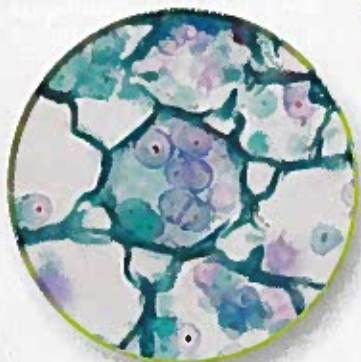
The results of those 47 cell cycles are truly amazing. The human body contains hundreds of distinctly different cell types, and every one of them develops from the single cell that starts the process. How do the cells get to be so different from each other?

### From One Cell to Many

🔑 How do cells become specialized for different functions?

Each of us started life as just one cell. So, for that matter, did your pet dog, an earthworm, and the petunia on the windowsill. These living things pass through a developmental stage called an **embryo**, from which the adult organism is gradually produced. During the development process, an organism's cells become more and more differentiated and specialized for particular functions. **Figure 10–18** shows some of the specialized cells found in the roots, stems, and leaves of a plant.

**FIGURE 10–18** Specialized Plant Cells



Cells that store sugar




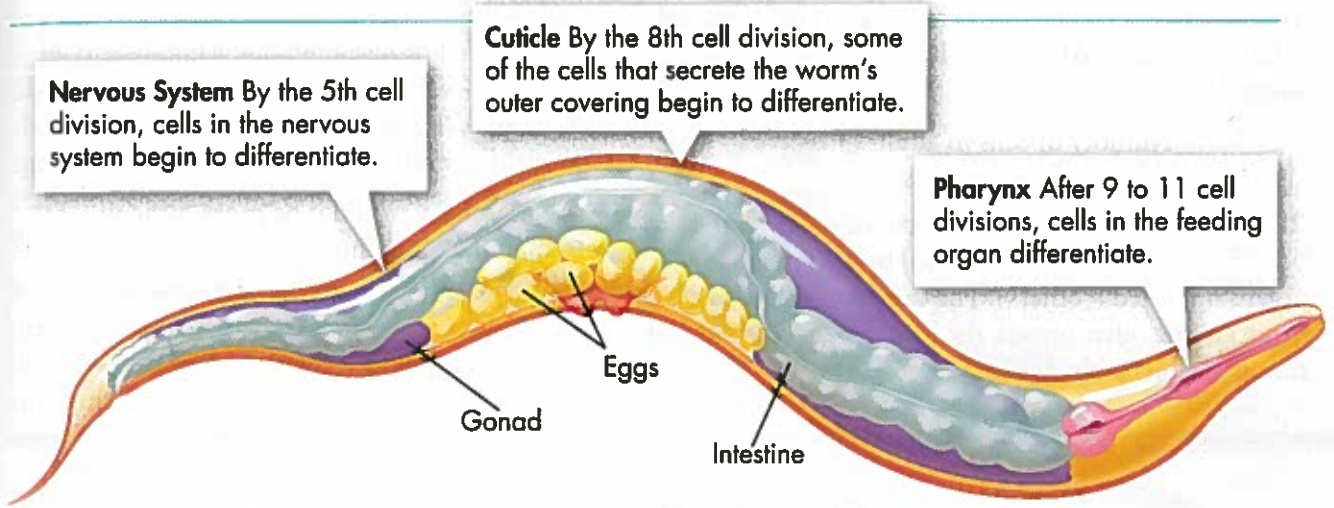
Cells that transport materials



Cells that carry out photosynthesis



**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 types of cells. 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.



**FIGURE 10-19 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.

**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 10-19 shows when some of the cells found in the adult begin to differentiate during development. Each and every time a new worm develops, the process is the same, resulting in 959 cells with precisely determined functions.

**Differentiation in Mammals** Other organisms, including mammals like us, 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 become other types of cells.

**In Your Notebook** Starting with a single cell, calculate how many cells might result after 4, 8, and 10 cell divisions.

# Analyzing Data

## Cellular Differentiation of *C. elegans*

The adult microscopic worm *C. elegans* contains 959 cells. The data table shows some of the different cell types in this worm. Copy the data table into your notebook and answer the following questions.

**1. Calculate** Calculate the percentage of the total cell number represented by each tissue or organ listed by using this formula:

$$\frac{\text{Number of cells in adult}}{\text{Total number of cells}} \times 100$$

**2. Calculate** Find both the number of cells and the percentage of the total represented by cells in tissues or organs not listed ("other"). The category includes cells from, among other organs, the intestine. Record the results in your table. **MATH**

| Cell Type                         | Number of Cells in Adult | Percent of Total |
|-----------------------------------|--------------------------|------------------|
| Cuticle                           | 213                      | 22%              |
| Gonad (excluding germ line cells) | 143                      |                  |
| Mesoderm muscle                   | 81                       |                  |
| Pharynx                           | 80                       |                  |
| Other                             |                          |                  |

**3. Infer** Why does *C. elegans* make an ideal model for studying cellular differentiation?

**4. Infer** Why would it be more difficult to map the differentiation patterns in a different organism, such as a mammal?

## Stem Cells and Development

**Key** What are stem cells?

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. Biologists say that such a cell 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 extraembryonic 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.


**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 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 RIP uh tunt). Cells that are **pluripotent** can develop into most, but not all, of the body's cell types. They cannot form the tissues surrounding the embryo.

### MYSTERY CLUE

Some adult salamander cells never completely differentiate. What ability do these cells retain?



**In Your Notebook** Look up the roots that form the words totipotent, pluripotent, and multipotent. How do the roots relate to each cell's ability to differentiate?

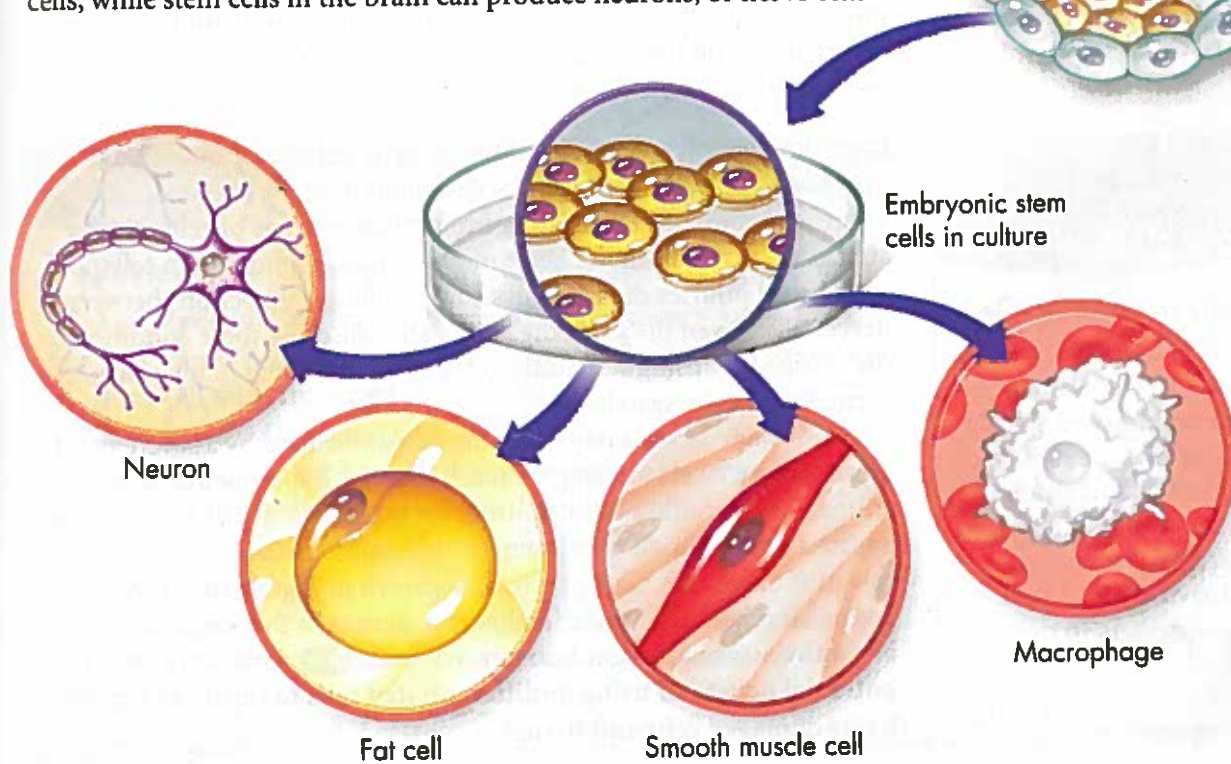
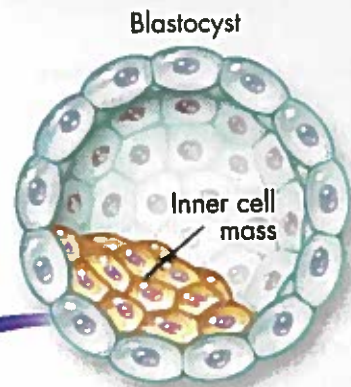
**Stem Cells**  The unspecialized cells from which differentiated cells develop are known as stem cells. As the name implies, stem cells sit at the base of a branching “stem” of development from which different cell types form. Because of their potential to develop into other cell types, stem cells are the subject of intense interest by researchers around the world.

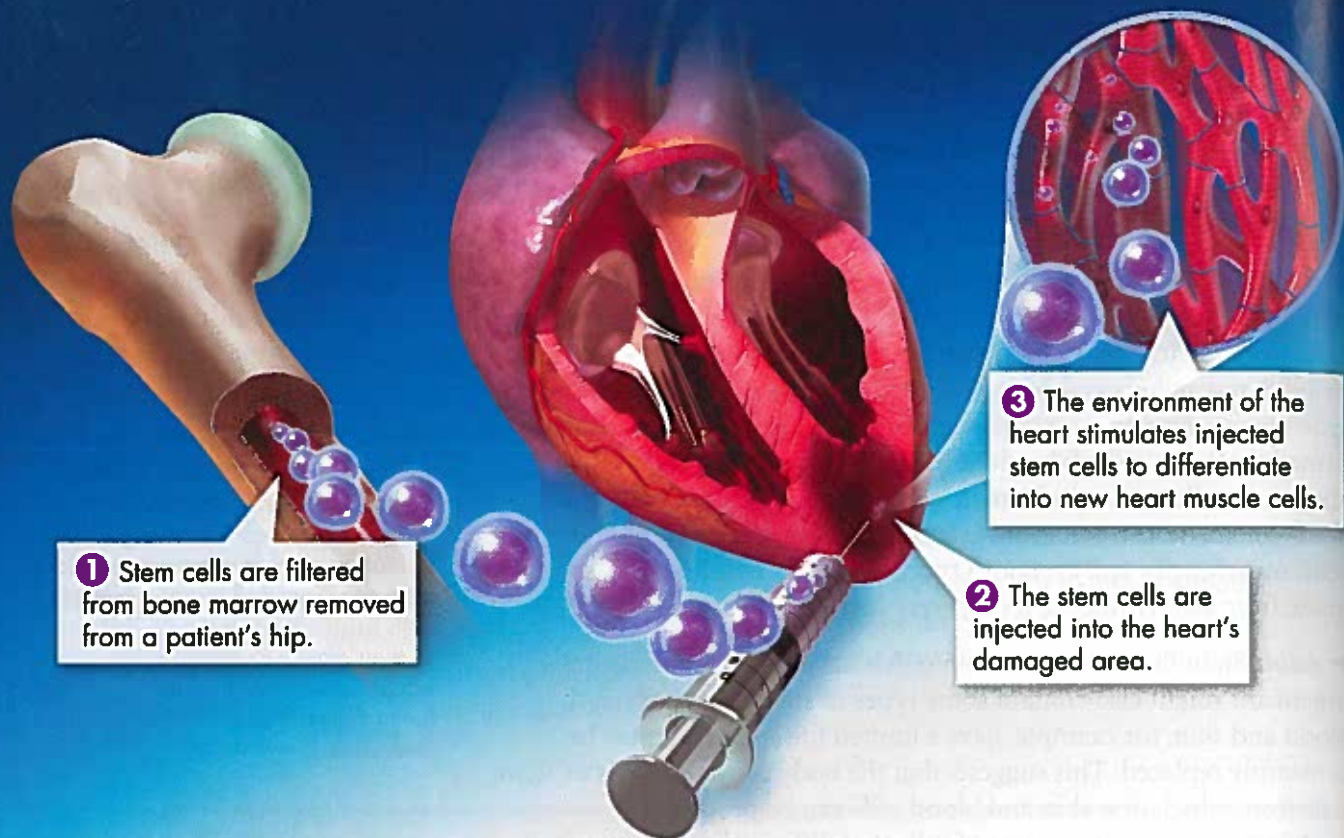
► **Embryonic Stem Cells** As you have seen, the pluripotent stem cells of the inner cell mass eventually produce all of the cells of the body. Embryonic stem cells are pluripotent cells found in the early embryo. In 1998, researchers at the University of Wisconsin found a way to grow these embryonic stem cells in culture. Their experiments confirmed that such cells did indeed have the capacity to produce just about any cell type in the human body. In fact, scientists have managed to coax mouse embryonic stem cells to differentiate into nerve cells, muscle cells, and even into sperm and egg cells. Recently, sperm made from embryonic stem cells were used to generate live mice.

► **Adult Stem Cells** For years, biologists have suspected that adult organisms might also contain some types of stem cells. Cells in the blood and skin, for example, have a limited life span and must be constantly replaced. This suggests that the body contains pools of stem cells from which new skin and blood cells can be produced.

Adult stem cells are groups of cells that differentiate to renew and replace cells in the adult body. Because of their more limited potential, adult stem cells are referred to as **multipotent** (muhl TIP uh tunt), meaning that they can develop into many types of differentiated cells. Typically, stem cells of a given organ or tissue produce only the types of cells that are unique to that tissue. For example, adult stem cells in the bone marrow can develop into several different types of blood cells, while stem cells in the brain can produce neurons, or nerve cells.

**FIGURE 10-20 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, these cells are known as embryonic stem cells.





**FIGURE 10-21** A Possible 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. **Infer** How would the fate of the stem cells change after they are moved from the bone marrow to the heart?

## Frontiers in Stem Cell Research


**➡** What are some possible benefits and issues associated with stem cell research?

Understanding how stem cells retain the capacity to differentiate into so many cell types is an important unsolved problem in biology. Scientists would like to learn exactly which signals tell a cell to become specialized, and how other cells remain multipotent.


**Potential Benefits** Basic research on stem cells takes on a special urgency in light of the importance it might have for human health. There are many causes of damage to particular types of cells. Heart attacks destroy cells in the heart muscle, strokes injure brain cells, and spinal cord injuries cause paralysis by breaking connections between nerve cells. Given the suffering and death caused by these conditions, the prospect of using stem cells to repair such cellular damage has excited medical researchers.

Many hope to see a day when the damage caused by a severe heart attack can be reversed using stem cell therapy. Experiments using animals suggest that several approaches show promise of success. One approach might be to inject stem cells from the patient's bone marrow into the heart's damaged area, as shown in Figure 10-21. Another approach might be to inject embryonic stem cells that might eventually differentiate into new heart muscle cells. **➡** Stem cells offer the potential benefit of using undifferentiated cells to repair or replace badly damaged cells and tissues.

**Ethical Issues** Because adult stem cells can be obtained directly from the body of a willing donor, research with these cells has raised few ethical questions to date. This is not the case with embryonic stem cells, which are generally obtained from very early embryos.

Most techniques for harvesting embryonic stem cells cause the destruction of an embryo. For this reason, individuals who regard the embryo as entitled to the rights and protections of any human being object to such work. This concern has made government funding of embryonic stem cell research an important political issue. Groups seeking to protect embryos 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.**

It is possible, however, that in the not-too-distant future, both ethical concerns will be addressed with a technological solution. Some recent experiments have suggested that there may be ways to extract a small number of stem cells from an early embryo without damaging the embryo itself. Other experiments have shown that it may be possible to switch “on” a small number of genes that would then cause adult cells to mimic pluripotent embryonic stem cells. Such a technique would do away with the need to involve embryos at all. It also might make it possible to tailor specific therapies to the needs of each individual patient. Approaches like these, if successful, might allow potentially lifesaving research to go forward while avoiding any destruction of embryonic life.

 **In Your Notebook** Make a two-column chart that lists the benefits and issues related to stem cell research.

## **BUILD** Vocabulary

**ACADEMIC WORDS** The word **harvest** is the act or process of gathering. Scientists who harvest stem cells are gathering the cells.

## 10.4 Assessment

### Review Key Concepts

- Review** What happens during differentiation?
  - Apply Concepts** What does “mapping” refer to in the process of cell differentiation?
- Review** What are stem cells?
  - Compare and Contrast** How are embryonic stem cells and adult stem cells alike? How are they different?
- Review** Summarize the potential benefits and issues of stem cell research.
  - Form an Opinion** How might technological advances help address the ethical concerns surrounding stem cell research?

### Apply the **Big** idea

#### Cellular Basis of Life

- 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.