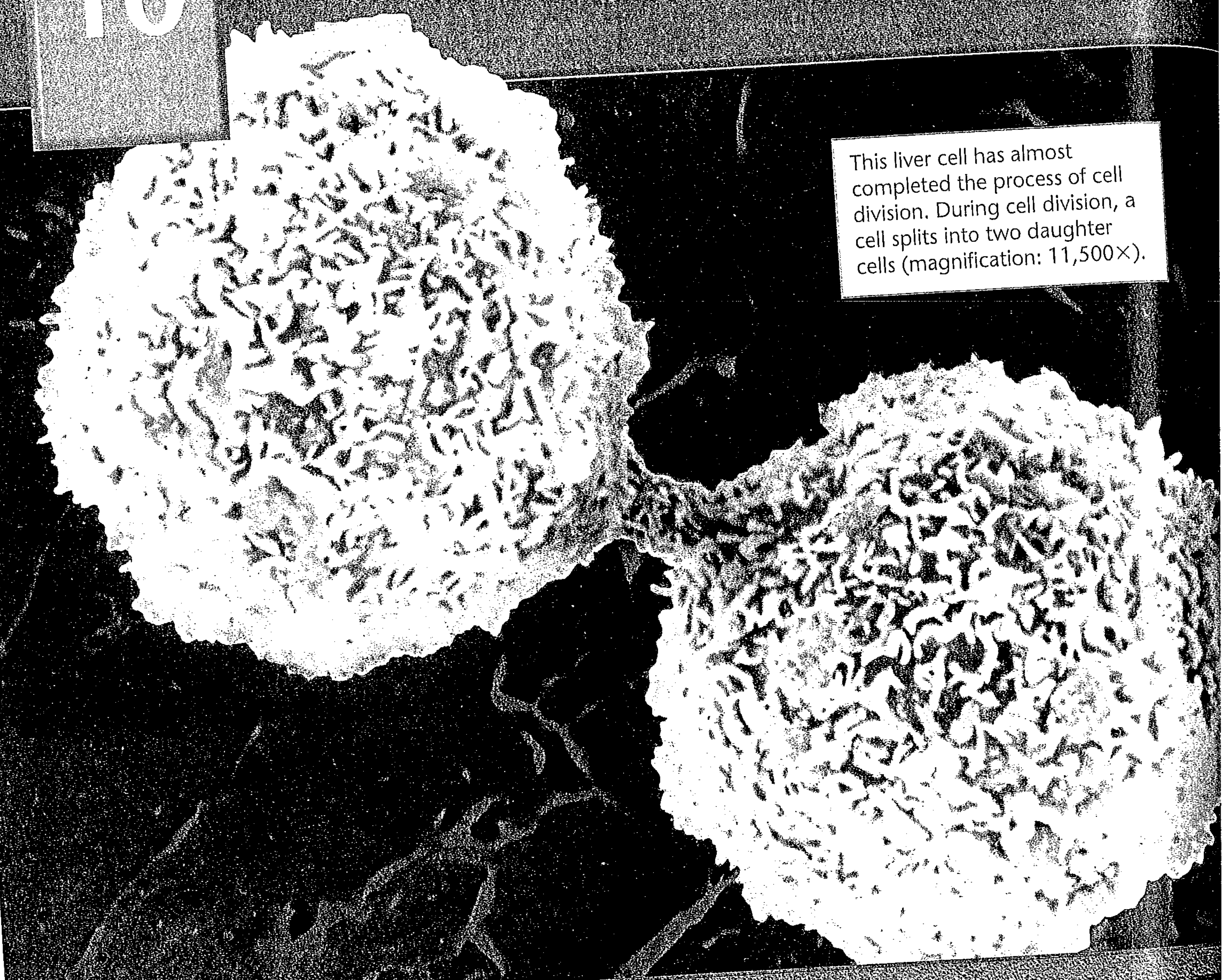
CHAPTER 10

Cell Growth and Division



This liver cell has almost completed the process of cell division. During cell division, a cell splits into two daughter cells (magnification: 11,500×).

Inquiry Activity

How do organisms grow?

Procedure

1. Use a microscope to compare the sizes of similar cells in large and small plants. For example, you might compare the leaf cells of grass to the leaf cells of a tree. Be sure to use the same magnification when comparing the sizes of the cells.
2. Use a microscope to compare the sizes of cells in similar tissues from small and large animals, such as muscle tissue from a frog and from a human.

Think About It

1. **Observing** Are the cells of the small plant larger or smaller than those of the large plant? Are the cells of the small animal larger or smaller than those of the large animal?
2. **Comparing and Contrasting** Make a general statement that compares the number and size of cells in small organisms to those in larger organisms.

10–1 Cell Growth

When a living thing grows, what happens to its cells? Does an animal 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. On average, the cells of an adult animal are no larger than those of a young animal—there are just more of them.

Limits to Cell Growth

There are two main reasons why cells divide rather than continuing to grow indefinitely. **The larger a cell becomes, the more demands the cell places on its DNA. In addition, the cell has more trouble moving enough nutrients and wastes across the cell membrane.**

DNA "Overload" As you may recall, the information that controls a cell's function is stored in a molecule known as DNA. In eukaryotic cells, DNA is found in the nucleus of the cell. When a cell is small, the information stored in that DNA is able to meet all of the cell's needs. But as a cell increases in size, it usually does not make extra copies of DNA. If a cell were to grow without limit, an "information crisis" would occur.

To help understand why a larger cell has a more difficult time functioning efficiently than a smaller cell, compare the cell to a growing town. Suppose a small town has a library with a few thousand books. If more people move into the town, the town will get larger. There will be more people borrowing books, and sometimes people may have to wait to borrow popular titles. Similarly, a larger cell would have to make greater demands on its available genetic "library." In time, the cell's DNA would no longer be able to serve the increasing needs of the growing cell.

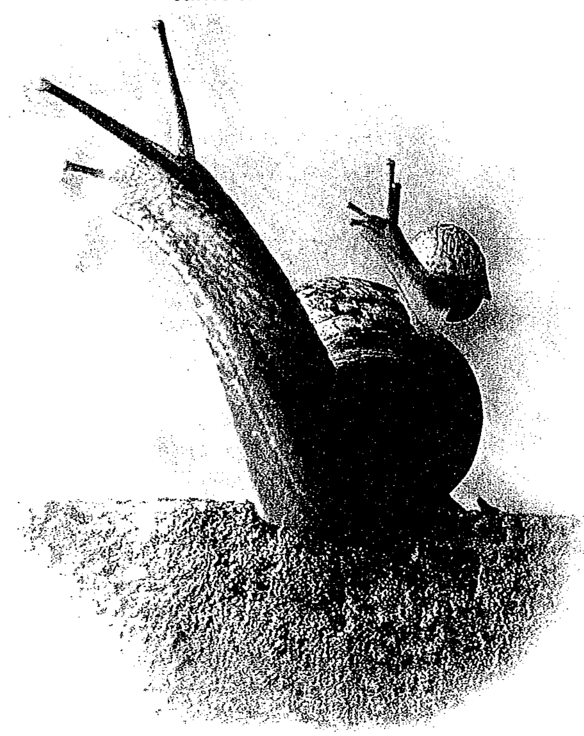
Exchanging Materials There is another reason why the size of cells is limited. You may recall that food, oxygen, and water enter a cell through its cell membrane. Waste products leave in the same way. The rate at which this exchange takes place depends on the surface area of the cell, which is the total area of its cell membrane. However, 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 volume and its surface area is the key to understanding why cells must divide as they grow.

Guide for Reading

Key Concept
- What problems does growth cause for cells?

Vocabulary
cell division

Reading Strategy: Asking Questions Before reading this section, rewrite each blue heading as a *what, where,* or *how* question. Then, as you read, fill in the answer to each question.



▼ **Figure 10–1** Living things grow by producing more cells. Although the adult snail is larger than the young snail, the cells of both are the same size.

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Ratio of Surface Area to Volume Imagine a cell that is shaped like a cube, like those in **Figure 10–2.** If this cell has a length of 1 cm, its surface area would be equal to length × width × number of sides, or 1 cm × 1 cm × 6 = 6 cm^2. The volume of the cell would be equal to length × width × height, or 1 cm × 1 cm × 1 cm = 1 cm^3. To obtain the ratio of surface area to volume, divide the surface area by the volume. In this case, the ratio of surface area to volume would be 6 / 1, or 6 : 1.

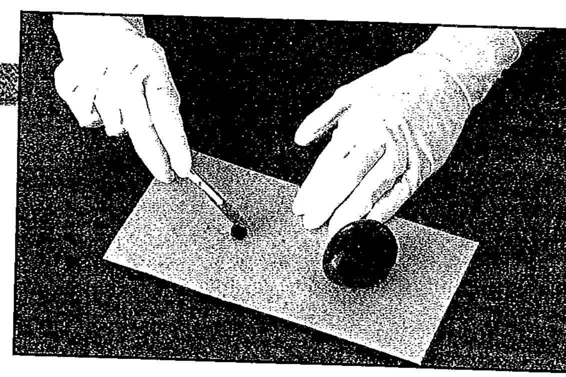
If the length of the cell doubled, what would happen to the cell's surface area compared to its volume? The cell's surface area would be equal to 2 cm × 2 cm × 6 = 24 cm^2. The volume would be equal to 2 cm × 2 cm × 2 cm = 8 cm^3. The cell's ratio of surface area to volume would be 24 / 8, or 3 : 1.

What if the length of the cell triples? The cell's surface area now would be 3 cm × 3 cm × 6 = 54 cm^2. The volume would be 3 cm × 3 cm × 3 cm = 27 cm^3. The ratio of surface area to volume would be 54 / 27, or 2 : 1.

Note that the volume increases much more rapidly than the surface area, causing the ratio of surface area to volume to decrease. This decrease creates serious problems for the cell.

To use the town analogy again, suppose that the small town has a two-lane main street. As the town grows, more people will begin to use this street. The main street leading through town, however, has not increased in size. As a result, people will encounter more traffic as they enter and leave the town. A cell that continues to grow larger would experience similar problems.

Quick Lab



What limits the sizes of cells?

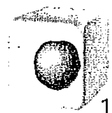
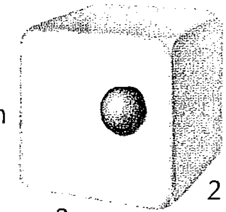
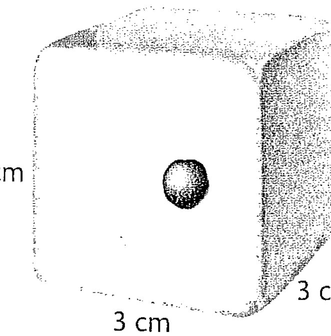
Materials 2 peeled hard-boiled eggs, blue food coloring, 150-mL beaker, scalpel, spoon, paper towels, metric ruler

Procedure

1. Put on your plastic gloves and apron. Place 100 mL of water in a beaker. Add 10 drops of blue food coloring, and stir with a spoon. **CAUTION:** *Food coloring may stain hands and clothing.*
2. Use the scalpel to cut through the middle of 1 hard-boiled egg. **CAUTION:** *Be careful with the scalpel.* Remove the yolk. Cut an 8-mm cube from the thickest part of the egg white.
3. Place the egg cube and a peeled hard-boiled egg gently into the beaker of food coloring and water. Allow the eggs to sit in the beaker for 10 minutes.
4. After 10 minutes, use a spoon to carefully remove the egg cube and the whole egg from the beaker, and place them on a paper towel. Cut the egg cube in half. Clean the scalpel blade and cut the whole egg in half. Measure how far the blue color penetrated the egg cube and the whole egg.

Analyze and Conclude

1. **Observing** How close to the centers of the egg cube and the whole egg did the color reach?
2. **Using Models** Compare the whole egg and the egg cube to cells to explain why a cell cannot continue to grow indefinitely.

Ratio of Surface Area to Volume in Cells			
Cell Size	 1 cm 1 cm 1 cm	 2 cm 2 cm 2 cm	 3 cm 3 cm 3 cm
Surface Area (length x width x 6)	1 cm x 1 cm x 6 = 6 cm^2	2 cm x 2 cm x 6 = 24 cm^2	3 cm x 3 cm x 6 = 54 cm^2
Volume (length x width x height)	1 cm x 1 cm x 1 cm = 1 cm^3	2 cm x 2 cm x 2 cm = 8 cm^3	3 cm x 3 cm x 3 cm = 27 cm^3
Ratio of Surface Area to Volume	6 / 1 = 6 : 1	24 / 8 = 3 : 1	54 / 27 = 2 : 1

▲ **Figure 10–2** As the length of a cell increases, its volume increases faster than its surface area. **The resulting decrease in the cell's ratio of surface area to volume makes it more difficult for the cell to move needed materials in and waste products out.**

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 one reason why cells do not grow much larger even if the organism of which they are a part 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 storage because each daughter cell gets one complete set of genetic information. Thus, each daughter cell receives its own genetic "library." Cell division also solves the problem of increasing size by reducing cell volume. Each daughter cell has an increased ratio of surface area to volume. This allows efficient exchange of materials with the environment.

10–1 Section Assessment

1. **Key Concept** Give two reasons why cells divide.
2. How is a cell's DNA like the books in a library?
3. As a cell increases in size, which increases more rapidly, its surface area or its volume?
4. **Critical Thinking Calculating** Calculate the surface area, volume, and ratio of surface area to volume of an imaginary cubic cell measuring 4 cm on each side.

Focus on the BIG Idea

Cellular Basis of Life
Select two cell organelles and describe how their functions might be impaired if the cell were to become too large. A review of Chapter 7 may help you with this task.

10–2 Cell Division

Guide for Reading

Key Concepts
- What are the main events of the cell cycle?
- What are the four phases of mitosis?

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

Reading Strategy: Outlining As you read this section, outline the major events of the cell cycle. Write a few sentences to describe the activity of chromosomes as they progress through each part of the cell cycle.

What do you think would happen if a cell were simply to split into two, without any advance preparation? Would each daughter cell have everything it needed to survive? Because each cell has only one set of genetic information, the answer is no. Every cell must first copy its genetic information before cell division begins. Each daughter cell then gets a complete copy of that information.

In most prokaryotes, the rest of the process of cell division is a simple matter of separating the contents of the cell into two parts. In eukaryotes, cell division is more complex and occurs in two main stages. The first stage, division of the cell nucleus, is called **mitosis** (my-TOH-sis). The second stage, division of the cytoplasm, is called **cytokinesis** (sy-toh-kih-NEE-sis).

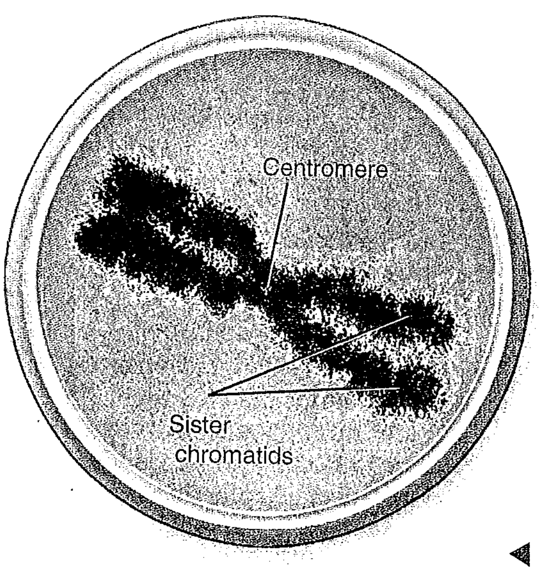
Many organisms, especially unicellular ones, reproduce by means of mitosis and cytokinesis. Reproduction by mitosis is classified as asexual, since the cells produced by mitosis are genetically identical to the parent cell. Mitosis is also the source of new cells when a multicellular organism grows and develops. In humans, for example, mitosis begins shortly after the egg is fertilized, producing the vast numbers of cells needed for the embryo to take form.

Chromosomes

In eukaryotic cells, the genetic information that is passed on from one generation of cells to the next is carried by chromosomes. Chromosomes are made up of DNA—which carries the cell's coded genetic information—and proteins. The cells of every organism have a specific number of chromosomes. The cells of fruit flies, for example, have 8 chromosomes; human cells have 46 chromosomes; and carrot cells have 18 chromosomes.

Chromosomes are not visible in most cells except during cell division. This is because the DNA and protein molecules that make up the chromosomes are spread throughout the nucleus. At the beginning of cell division, however, the chromosomes condense into compact, visible structures that can be seen through a light microscope.

Well before cell division, each chromosome is replicated, or copied. Because of this, each chromosome consists of two identical "sister" **chromatids** (KROH-muh-tidz), as shown in **Figure 10–3.** When the cell divides, the "sister" chromatids separate from each other. One chromatid goes to each of the two new cells.



(magnification: 20,000×)

Figure 10–3 This is a human chromosome shown as it appears through an electron microscope. Each chromosome has two sister chromatids attached at the centromere. **Inferring** *Why is it important that the sister chromatids are identical?*

Each pair of chromatids is attached at an area called the centromere (SEN-troh-meer). **Centromeres** are usually located near the middle of the chromatids, although some lie near the ends. A human body cell entering cell division contains 46 chromosomes, each of which consists of two chromatids.

The Cell Cycle

At one time, biologists described the life of a cell as one 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, and use a concept known as the cell cycle to represent recurring events in the life of the cell. The **cell cycle** is the series of events that cells go through as they grow and divide. **During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells, each of which then begins the cycle again.** The cell cycle is shown in **Figure 10–4.**

The cell cycle consists of four phases. Mitosis and cytokinesis take place during the M phase. Chromosome replication, or synthesis, takes place during the S phase. When the cell copies the chromosomes, it makes a duplicate set of DNA. Between the M and S phases are G_1 and G_2. The *G* in the names of these phases stands for "gap," but the G_1 and G_2 are definitely not periods when nothing takes place. They are actually periods of intense growth and activity.

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Events of the Cell Cycle

During the normal cell cycle, interphase can be quite long, whereas the process of cell division takes place quickly. Interphase is divided into three phases: G_1, S, and G_2.

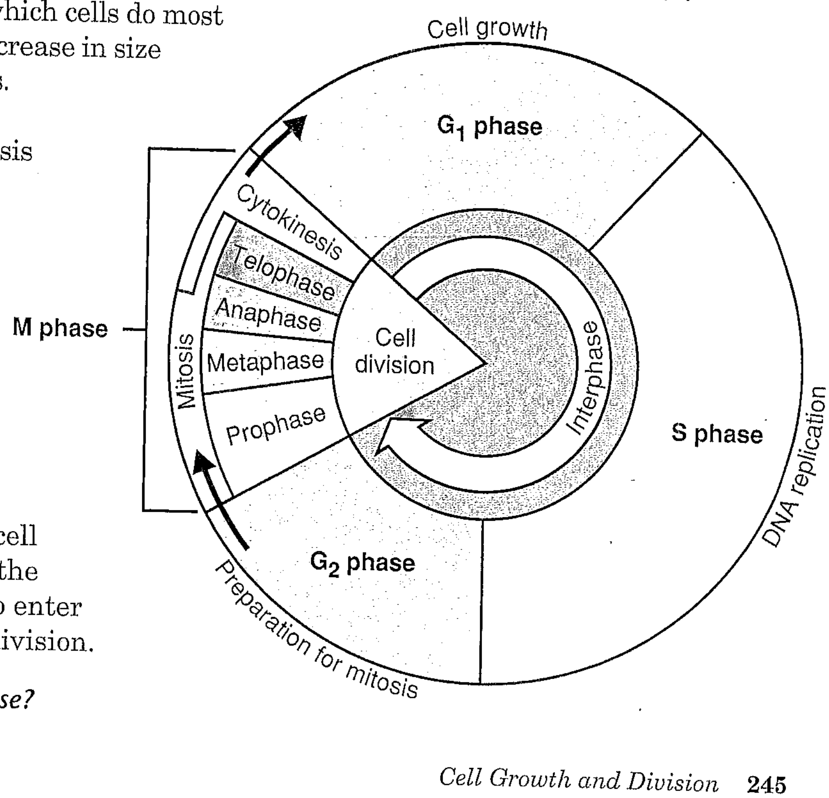
The G_1 phase is a period of activity in which cells do most of their growing. During this phase, cells increase in size and synthesize new proteins and organelles.

G_1 is followed by the S phase, in which chromosomes are replicated and the synthesis of DNA molecules takes place. Key proteins associated with the chromosomes are also synthesized during the S phase. Usually, once a cell enters the S phase and begins the replication of its chromosomes, it completes the rest of the cell cycle.

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

CHECKPOINT *What happens during the G_1 phase?*

Figure 10–4 **During the cell cycle, the cell grows, replicates its DNA, and divides into two daughter cells.** DNA synthesis takes place during the S phase. Cell division takes place during the M phase. G_1 and G_2 are gap phases.



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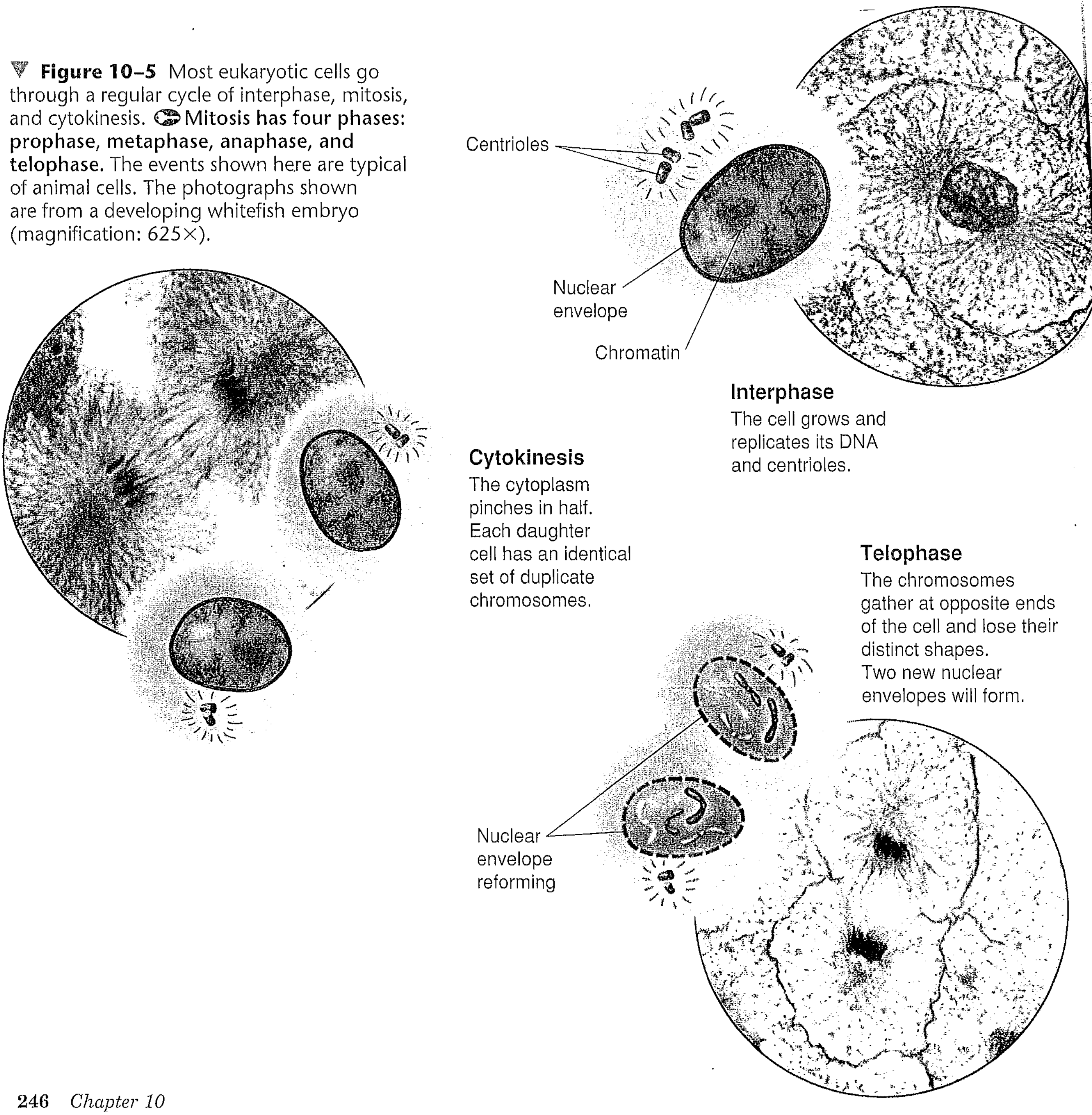
Mitosis

Biologists divide the events of mitosis into four phases: prophase, metaphase, anaphase, and telophase. Depending on the type of cell, the four phases of mitosis may last anywhere from a few minutes to several days. As you read about each phase of mitosis, look at **Figure 10–5.**

Prophase The first and longest phase of mitosis, **prophase,** can take as much as 50 to 60 percent of the total time required to complete mitosis. During prophase, the chromosomes become visible. The **centrioles** (SEN-tree-ohlz), two tiny structures located in the cytoplasm near the nuclear envelope, separate and take up positions on opposite sides of the nucleus.

▼ **Figure 10–5** Most eukaryotic cells go through a regular cycle of interphase, mitosis, and cytokinesis. **Mitosis has four phases: prophase, metaphase, anaphase, and telophase.** The events shown here are typical of animal cells. The photographs shown are from a developing whitefish embryo (magnification: 625×).



The centrioles lie in a region called the centrosome that helps to organize the **spindle,** a fanlike microtubule structure that helps separate the chromosomes. During prophase, the condensed chromosomes become attached to fibers in the spindle at a point near the centromere of each chromatid. Interestingly, plant cells do not have centrioles, but still organize their mitotic spindles from similar regions.

Near the end of prophase, the chromosomes coil more tightly. In addition, the nucleolus disappears, and the nuclear envelope breaks down.

CHECKPOINT *What is the function of the spindle?*

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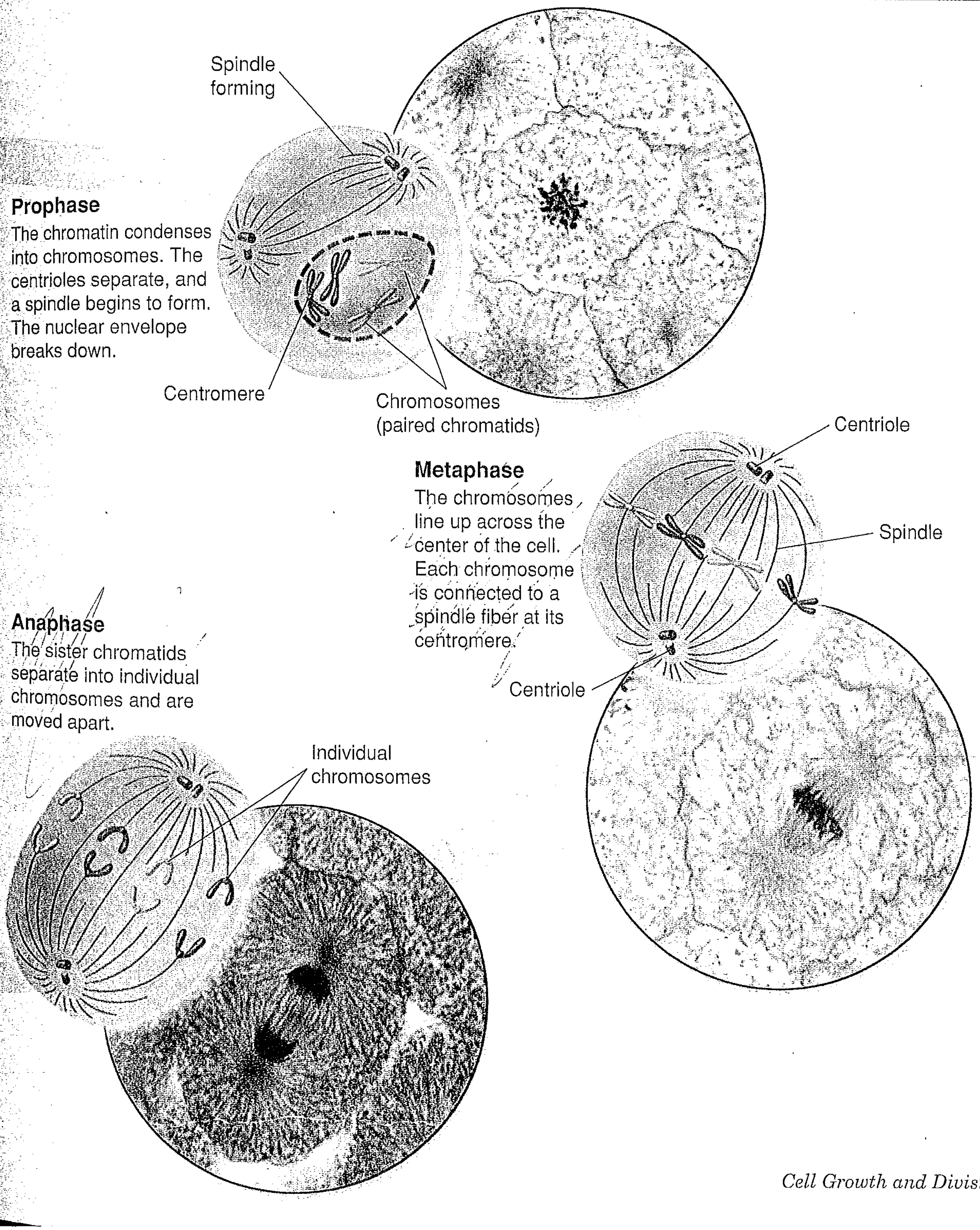


Metaphase The second phase of mitosis, **metaphase,** often lasts only a few minutes. During metaphase, the chromosomes line up across the center of the cell. Microtubules connect the centromere of each chromosome to the two poles of the spindle.

Anaphase **Anaphase** is the third phase of mitosis. During anaphase, the centromeres that join the sister chromatids split, allowing the sister chromatids to separate and become individual chromosomes. The chromosomes continue to move until they have separated into two groups near the poles of the spindle. Anaphase ends when the chromosomes stop moving.

Telophase Following anaphase is **telophase,** the fourth and final phase of mitosis. In telophase, the chromosomes, which were distinct and condensed, begin to disperse into a tangle of dense material. 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 complete.

✓ CHECKPOINT *What happens during anaphase?*

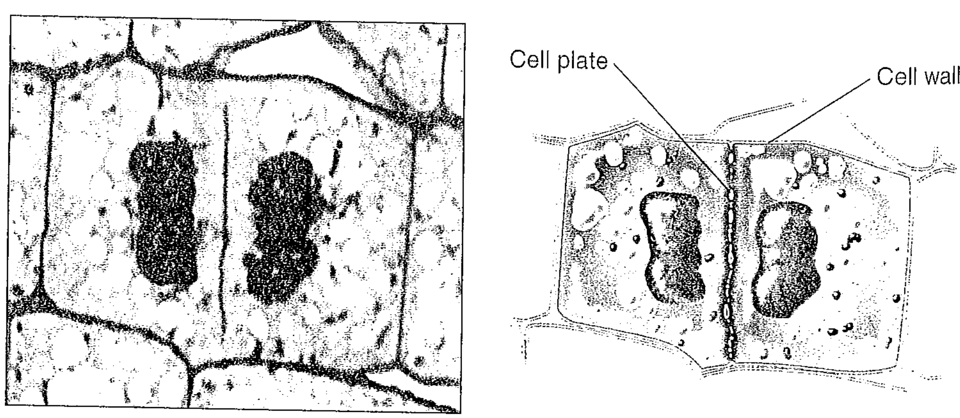
Cytokinesis

As a result of mitosis, two nuclei—each with a duplicate set of chromosomes—are formed, usually within the cytoplasm of a single cell. 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.

Cytokinesis can take place in a number of ways. 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. In plants, a structure known as the cell plate forms midway between the divided nuclei, as shown in **Figure 10–6.** The cell plate gradually develops into a separating membrane. A cell wall then begins to appear in the cell plate.

Word Origins

Cytokinesis comes from the Greek words *kytos,* meaning "hollow vessel," and *kinesis,* meaning "motion." The prefix *cyto-* refers to cells, so *cytokinesis* means movement within the cell. **What do you think the term *cytotoxic* means?**



(magnification: 2200×)

Figure 10–6 During cytokinesis in plant cells, the cytoplasm is divided by a cell plate. The thin line you can see between the two dark nuclei in this electron micrograph of onion cells dividing is the cell plate forming. **Interpreting Graphics** *What structure forms between the divided nuclei?*

Analyzing Data

Life Spans of Human Cells

Like all organisms, cells have a given life span from birth to death. In multicellular organisms, such as humans, the health of the organism depends on cells not exceeding their life span. This is especially true of cells that tend to divide rapidly. If these cells did not die on schedule, overcrowding of cells would occur, causing uncontrolled growth that would be life-threatening.

The data table shows the life spans of various human cells. It also contains information about the ability of the cells to multiply through cell division.

1. **Inferring** White blood cells help protect the body from infection and disease-producing organisms. How might their function relate to their life span?
2. **Comparing and Contrasting** Based on the data, how are the consequences of injuries to the heart and spinal cord similar to each other? How are they different from the consequences of injuries to smooth muscle?
3. **Formulating Hypotheses** Propose a hypothesis to account for the data related to the cell life spans of the lining of the esophagus, small intestine, and large intestine.

Life Spans of Various Human Cells

Cell Type	Life Span	Cell Division
Lining of esophagus	2–3 days	Can divide
Lining of small intestine	1–2 days	Can divide
Lining of large intestine	6 days	Can divide
Red blood cells	Less than 120 days	Cannot divide
White blood cells	10 hours to decades	Many do not divide
Smooth muscle	Long-lived	Can divide
Cardiac (heart) muscle	Long-lived	Cannot divide
Skeletal muscle	Long-lived	Cannot divide
Neuron (nerve cell)	Long-lived	Most do not divide

4. **Going Further** Cancer is a disease related to cell life span and cell division. If cancer cells were added to the data table, predict what would be written under the columns headed "Life Span" and "Cell Division." Explain the reasoning underlying your predictions.

10–2 Section Assessment

1. **Key Concept** Name the main events of the cell cycle.
2. **Key Concept** Describe what happens during each of the four phases of mitosis.
3. Describe what happens during interphase.
4. What are chromosomes made of?
5. How do prokaryotic cells divide?
6. **Critical Thinking Comparing and Contrasting** How is cytokinesis in plant cells similar to cytokinesis in animal cells? How is it different?

Writing in Science

Creative Writing

Suppose you were small enough to hitch a ride on a chromosome located in a plant cell that goes through mitosis and cytokinesis. Describe what you would see happening during each phase of the process.

10–3 Regulating the Cell Cycle

Guide for Reading

Key Concepts
- How is the cell cycle regulated?
- How are cancer cells different from other cells?

Vocabulary
cyclin
cancer

Reading Strategy: Summarizing Summarizing helps you understand and remember what you read. Write a main-idea statement for each blue head. When you have finished the section, compare your statements with those in the study guide.

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

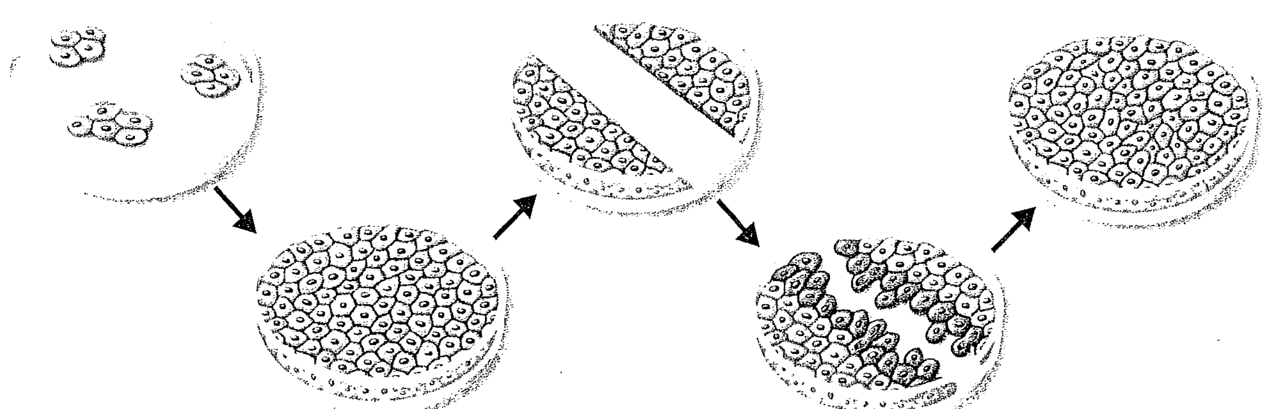
Controls on Cell Division

Scientists can observe the effects of controlled cell growth in the laboratory by placing some cells in a petri dish containing nutrient broth. The nutrient broth provides food for the cells. Most cells will grow until they form a thin layer covering the bottom of the dish, as shown in **Figure 10–7.** Then, the cells stop growing. When cells come into contact with other cells, they respond by not growing.

If cells are removed from the center of the dish, however, the cells bordering the open space will begin dividing until they have filled the empty space. These experiments show that the controls on cell growth and cell division can be turned on and off.

Something similar happens within the body. When an injury such as a cut in the skin or a break in a bone occurs, cells at the edges of the injury are stimulated to divide rapidly. This action produces new cells, starting the process of healing. When the healing process nears completion, the rate of cell division slows down, controls on growth are restored, and everything returns to normal.

Figure 10–7 Cells in a petri dish will continue to grow until they come into contact with other cells. **Applying Concepts** *What would happen if the cells continued to divide?*



Cell Cycle Regulators

For many years, biologists searched for a substance 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 cycle. In the early 1980s, biologists found the substance.

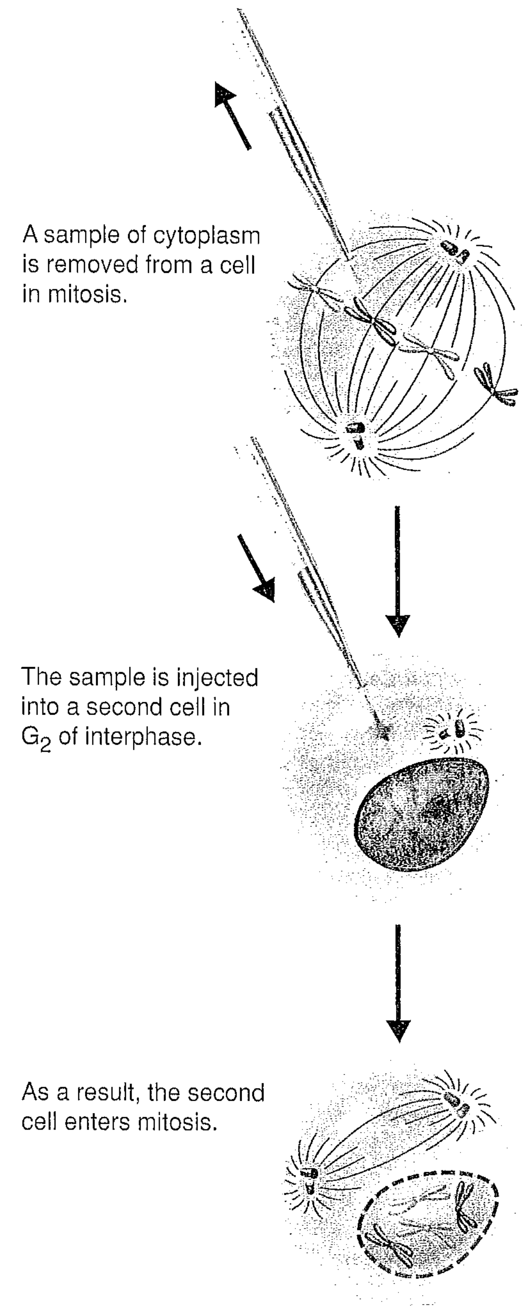
Several scientists, including Tim Hunt of Great Britain and Mark Kirschner of the United States, discovered that cells in mitosis contained a protein that when injected into a nondividing cell, would cause a mitotic spindle to form. Such an experiment is shown in **Figure 10–8.** To their surprise, they discovered that the amount of this protein in the cell rose and fell in time with the cell cycle. They decided to call this protein **cyclin** because it seemed to regulate the cell cycle. Investigators have since discovered a family of closely related proteins, known as cyclins, that are involved in cell cycle regulation. **Cyclins regulate the timing of the cell cycle in eukaryotic cells.**

The discovery of cyclins was just the beginning. More recently, dozens of other proteins have been discovered that also help to regulate the cell cycle. There are two types of regulatory proteins: those that occur inside the cell and those that occur outside the cell.

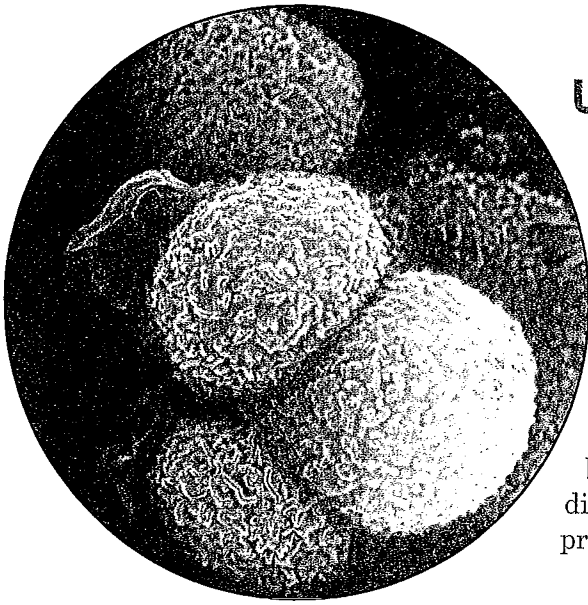
Internal Regulators Proteins that respond to events inside the cell are called internal regulators. Internal regulators allow the cell cycle to proceed only when certain processes have happened inside the cell. For example, several regulatory proteins make sure that a cell does not enter mitosis until all its chromosomes have been replicated. Another regulatory protein prevents a cell from entering anaphase until all its chromosomes are attached to the mitotic spindle.

External Regulators Proteins that respond to events outside the cell are called external regulators. External regulators direct cells to speed up or slow down the cell cycle. Growth factors are among the most important external regulators. They stimulate the growth and division of cells. Growth regulators are especially important during embryonic development and wound healing. Molecules found on the surfaces of neighboring cells often have an opposite effect, causing cells to slow down or stop their cell cycles. These signals prevent excessive cell growth and keep the tissues of the body from disrupting one another.

CHECKPOINT *What are cyclins?*



▲ **Figure 10–8** **The timing of the cell cycle is regulated by cyclins.** When cytoplasm from a cell in mitosis is injected into another cell, the second cell enters mitosis. The reason for this effect is a protein called cyclin, which triggers cell division.



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▲ **Figure 10–9** **Cancer cells do not respond to the signals that regulate the growth of most cells.** Masses of cancer cells form tumors that can damage normal tissues. These cancer cells are from a tumor in the large intestine.

Discovery EDUCATION To find out more about how scientists study cancer, view track 3 "Skin Cancer: Deadly Cells" on the *BioDetectives* DVD.

Uncontrolled Cell Growth

Why is cell growth regulated so carefully? The principal reason may be that the consequences of uncontrolled cell growth in a multicellular organism are very severe. **Cancer,** a disorder in which some of the body's own 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, they divide uncontrollably and form masses of cells called tumors that can damage the surrounding tissues. Cancer cells may break loose from tumors and spread throughout the body, disrupting normal activities and causing serious medical problems or even death. **Figure 10–9** shows typical cancer cells.

What causes the loss of growth control that characterizes cancer? The various forms of cancer have many causes, including smoking tobacco, radiation exposure, and even viral infection. All cancers, however, have one thing in common: The control over the cell cycle has broken down. Some cancer cells will no longer respond to external growth regulators, while others fail to produce the internal regulators that ensure orderly growth.

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

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 Section Assessment

1. **Key Concept** What chemicals regulate the cell cycle? How do they work?
2. **Key Concept** What happens when cells do not respond to the signals that normally regulate their growth?
3. How do cells respond to contact with other cells?
4. Why can cancer be considered a disease of the cell cycle?
5. **Critical Thinking Formulating Hypotheses** Write a hypothesis about what you think would happen if cyclin were injected into a cell that was in mitosis.

Sharpen Your Skills

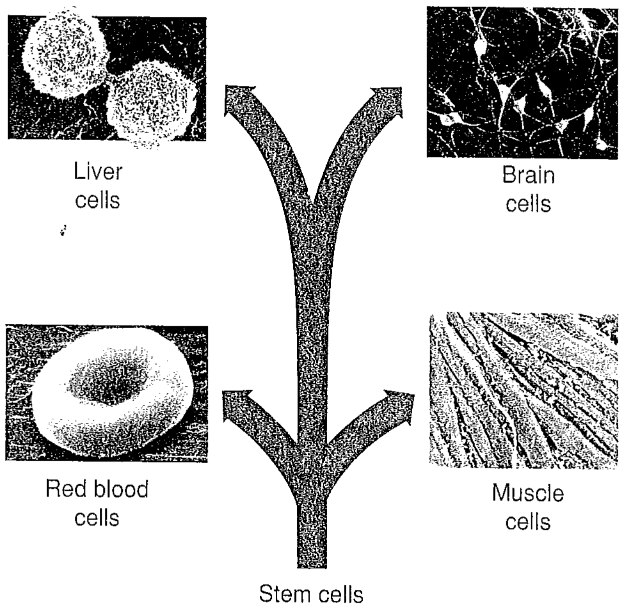
Problem Solving

Imagine that you are developing a drug that will inhibit the growth of cancer cells. Use your knowledge of the cell cycle to describe how the drug would target and prevent the multiplication of cancer cells. Use the Internet to compare your anticancer drug with those currently in use.

Technology & Society

Stem Cells: Promises and Problems

Where do the different cells and tissues in your body come from? Incredible as it seems, every cell was produced by mitosis from a small number of cells called stem cells. Stem cells are unspecialized cells that have the potential to differentiate—to become specialized in structure and function—into a wide variety of cell types. In early embryonic development, stem cells produce every tissue in the body. Evidence indicates that stem cells also are found in adults. Stem cells in the bone marrow, for example, produce more than a dozen types of blood cells, replacing those lost due to normal wear and tear.



Stem Cells in Medicine

Although your body produces billions of new cells every day, it is not always able to produce the right kind of cell to replace those damaged by injury or disease. For example, the body is not able to produce new neurons to repair serious spinal cord injuries, such as those that cause paralysis. Because of this, at present, there is no way for doctors to restore movement and feeling to people who are paralyzed.

Stem cells may be the perfect solution to this problem. Recently, researchers have found that implants of stem cells can reverse the effects of brain injuries in mice. There is hope that the same will hold true for humans and that stem cells might be used to reverse brain and spinal cord injuries. It also may be possible to use stem cells to grow new liver tissue, to replace heart valves, and to reverse the effects of diabetes.

Sources of Stem Cells

Human embryonic stem cells were first isolated in 1998 by scientists in Wisconsin. Many scientists are now experimenting with ways to produce such cells by transferring adult cell nuclei into the cytoplasms of egg cells. However, since these techniques use or produce early human embryos, these techniques raise serious moral and ethical questions. Because of such issues, embryonic stem cell research is highly controversial.

Researchers have also found that nerve, muscle, and liver cells sometimes can be grown from adult stem cells isolated from the bone marrow and other tissues in the body. Experiments such as these, although still in the early stages of development, may usher in a new era of therapy in which replacement tissue is grown from a person's own stem cells.

Research and Decide

Use library or Internet resources to learn more about stem-cell research. Then, write a brief report on how this technology will impact the future of medicine.

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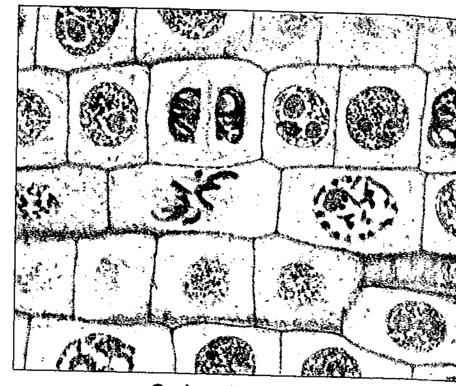
Exploration

Modeling the Phases of the Cell Cycle

In a growing root, the cells at the tip of the root are constantly dividing. Because each cell divides independently of the others, a root tip contains many cells at different phases of the cell cycle. This makes a root tip an excellent tissue in which to study the cell cycle. In this investigation, you will identify and describe the phases of the cell cycle in root tip cells.



Onion Root Tip
(magnification: 700×)

Problem What do the phases of the cell cycle look like in a typical plant cell?

Materials

- microscope
- prepared slides of onion root tips
- craft materials such as beads, yarn, and pipe cleaners
- tape or glue
- scissors

Skills Classifying, Using Models

Procedure

1. Obtain a prepared slide of an onion root tip. Hold the slide up to the light and find the pointed end of the root section. This is the root tip where cells were actively dividing.
2. Place the slide on the microscope stage with the root tip pointing away from you. Using the low-power objective, adjust the focus of the microscope until the root tip is clearly visible. Just above the root tip is a region that contains many new small cells. The larger cells of this region were in the process of dividing when the slide was made. These are the cells you will be observing.
3. Observe the boxlike cells that are arranged in rows. Scan across one row and down to the next row to compare the cells. The chromosomes of the cells have been stained to make them easily visible. Select one cell whose chromosomes are clearly visible. Switch to high power and sketch this cell.
4. Use the craft materials to make a model of the cell that you sketched, showing how its chromosomes are arranged.
5. Select at least four more cells whose internal appearances are different from the first cell you sketched. Switch to high power and sketch each of these cells. Repeat step 4 for each cell you sketch.
6. On a separate sheet of paper, make a copy of the data table shown. Choose 25 root tip cells at random and decide which phase of the cell cycle each is in. Record the number of cells in each phase in your copy of the data table. If you find that some cells appear to be between two phases, record those observations as well.
7. Look closely at your sketches and models. Arrange the models in order to represent the process of cell division.
8. Refer to **Figure 10–5** on pages 246 and 247 to determine whether you have ordered the phases of the cell cycle accurately. Correct the order of your models, if necessary. Label each of the models and sketches with the name of the phase it represents. Use the models to explain the process of cell division to another student.
9. Wash your hands with soap and warm water before you leave the lab.

Data Table

Phase	Number of Cells
Interphase	
Prophase	
Metaphase	
Anaphase	
Telophase	

Analyze and Conclude

1. **Analyzing Data** Do your results indicate that there were more cells in some phases than in others? Identify the most common phase(s) and explain what these differences in numbers of cells might mean.
2. **Drawing Conclusions** What evidence did you observe that shows mitosis is a continuous process, not a series of separate events?
3. **Using Models** Describe what is happening in each phase of your cell models.
4. **Using Models** Propose an alternative model to illustrate the same concept.
5. **Applying 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 process ensures that the normal number of chromosomes is restored after each cell division? During which part of the cell cycle does this process occur?

Go Further

Making Models In muscle cells, mitosis is not always followed by cell division. Instead, repeated cycles of mitosis result in long, tubular cells with many nuclei. Make a model that shows mitosis in a muscle cell.

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Share Your Data Online Enter your data on the number of cells in the phases of the cell cycle. Then, look at the data entered by other students. Based on the available data, were there more cells in some phases than in others? Why might your results differ from those of other students?

Chapter 10 Study Guide

10–1 Cell Growth

Key Concept

- The larger a cell becomes, the more demands the cell places on its DNA. In addition, the cell has more trouble moving enough nutrients and wastes across the cell membrane.

Vocabulary
cell division, p. 243

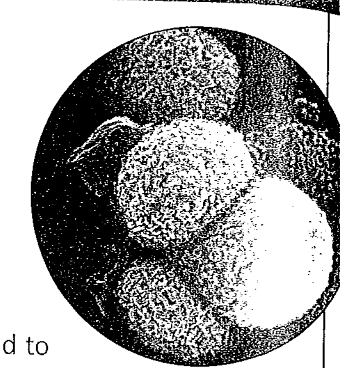
10–2 Cell Division

Key Concepts

- During the cell cycle, a cell grows, prepares for division, and divides to form two daughter cells, each of which then begins the cycle again.
- Biologists divide the events of mitosis into four phases: prophase, metaphase, anaphase, and telophase. Mitosis insures that each daughter cell has the same genetic information as the parent cell.
- During prophase in animal cells, the centrioles separate and take up positions on opposite sides of the nucleus. In addition, chromosomes condense and the spindle appears.
- During metaphase, the chromosomes line up across the center of the cell. Microtubules connect the chromosome to each pole of the spindle.
- During anaphase, the centromeres that join the sister chromatids split, and the sister chromatids separate and become individual chromosomes.
- In telophase, the chromosomes, which were distinct and condensed, uncoil and disperse as the nuclear envelope re-forms.
- Cytokinesis is the division of the cytoplasm.

Vocabulary
mitosis, p. 244
cytokinesis, p. 244
chromatid, p. 244
centromere, p. 245
interphase, p. 245
cell cycle, p. 245
prophase, p. 246
centriole, p. 246
spindle, p. 247
metaphase, p. 248
anaphase, p. 248
telophase, p. 248

10–3 Regulating the Cell Cycle



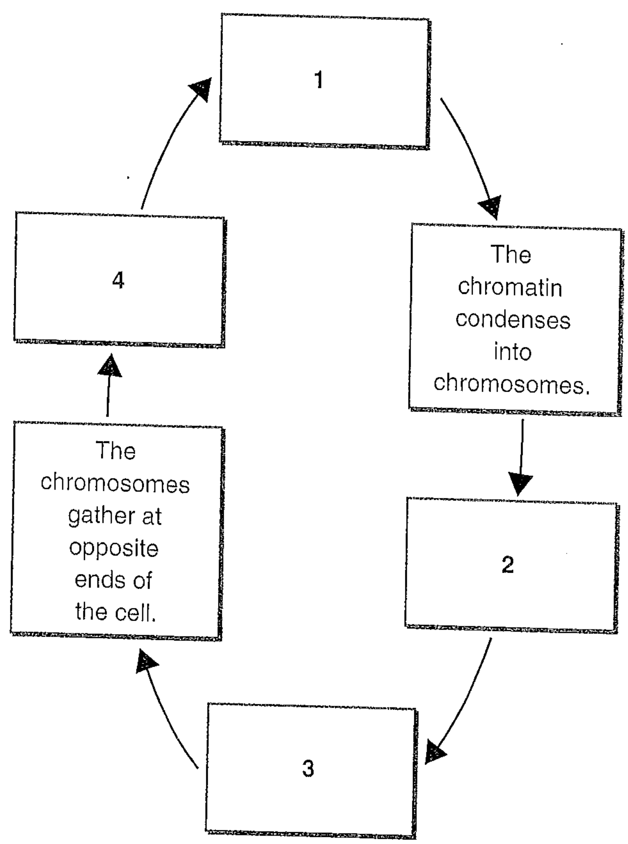
Key Concepts

- Cyclins regulate the timing of the cell cycle in eukaryotic cells.
- Cancer cells do not respond to the signals that regulate the growth of most cells.

Vocabulary
cyclin, p. 251
cancer, p. 252

Thinking Visually

Using the information in this chapter, complete the following cycle diagram of the cell cycle:



Chapter 10 Assessment

Reviewing Content

Choose the letter that best answers the question or completes the statement.

1. The rate at which materials enter and leave through the cell membrane depends on the cell's
   a. volume. c. mass.
   b. weight. d. surface area.

2. The process of cell division results in
   a. sister chromatids. c. two daughter cells.
   b. mitosis. d. unregulated growth.

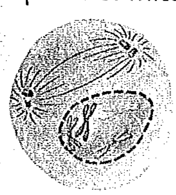
3. Sister chromatids are attached to each other at an area called the
   a. centriole. c. spindle.
   b. centromere. d. chromosome.

4. If a cell has 12 chromosomes, how many chromosomes will each of its daughter cells have after mitosis?
   a. 4 c. 12
   b. 6 d. 24

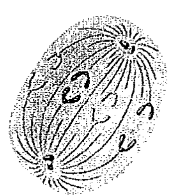
5. At the beginning of cell division, a chromosome consists of two
   a. centromeres. c. chromatids.
   b. centrioles. d. spindles.

6. The phase of mitosis during which chromosomes become visible and the centrioles separate from one another is
   a. prophase. c. metaphase.
   b. anaphase. d. telophase.

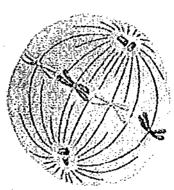
7. Which of the illustrations below best represents metaphase of mitosis?



a.



c.



b.

d.

8. The timing of the cell cycle in eukaryotic cells is believed to be controlled by a group of closely related proteins known as
   a. chromatids.
   b. cyclins.
   c. centromeres.
   d. centrioles.

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9. In the cell cycle, external regulators direct cells to
   a. speed up or slow down the cell cycle.
   b. remain unchanged.
   c. proceed and then stop the cell cycle.
   d. grow uncontrollably.

10. Uncontrolled cell division occurs in
   a. cancer.
   b. mitosis.
   c. cytokinesis.
   d. cyclin.

Understanding Concepts

11. Summarize what happens during the process of cell division.
12. Explain how a cell's DNA can limit the cell's size.
13. Describe what is meant by each of the following terms: cell volume, cell surface area, ratio of surface area to volume.
14. How is a cell's potential growth affected by its ratio of surface area to volume?
15. Describe how a cell's chromosomes change as a cell prepares to divide.
16. What is the relationship between interphase and cell division?
17. Summarize what happens during interphase.
18. Explain how the following terms are related to one another: DNA, centromere, chromosome, chromatid.
19. List the following events in the correct sequence, and describe what happens during each event: anaphase, metaphase, prophase, and telophase.
20. How does the number of chromosomes in the two new cells compare with the number in the original cell at the end of cell division?
21. Summarize what happens during the cell cycle.
22. When some cells are removed from the center of a tissue culture, will new cells replace the cells that were removed? Explain.
23. Describe the role of cyclins in the cell cycle.
24. Why is it important that cell growth in a multicellular organism be regulated so carefully?
25. How do cancer cells differ from noncancerous cells? How are they similar?

Chapter 10 Assessment

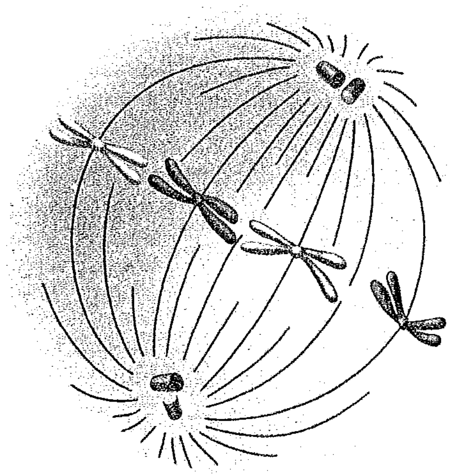
Critical Thinking

26. **Using Models** Use paper, blocks, or another material to create three-dimensional models demonstrating how the ratio of surface area to volume changes as the size of a cube changes.

27. **Calculating** Calculate the surface area, volume, and ratio of surface area to volume of an imaginary cubic cell measuring 5 mm on each side.

28. **Designing Experiments** A classmate suggests that temperature might affect the rate of mitosis in plant cells. Design an experiment to test this hypothesis.

29. **Interpreting Graphics** The diagram below shows a phase of mitosis. Use the diagram to answer the questions.



a. Identify the phase and indicate whether the cell most resembles that of a plant or an animal. Explain your answer.

b. The four chromosomes shown in the center of this cell each have two connected strands. Explain how the two strands on the same chromosome compare with regard to the genetic information they carry. In your answer, be sure to explain why this is important to the cell.

30. **Formulating Hypotheses** Some cells have several nuclei within the cytoplasm of a single cell. Considering the events in a typical cell cycle, which phase of the cell cycle is not operating when such cells form?

31. **Comparing and Contrasting** Describe the differences between cell division in an animal cell and cell division in a plant cell.

32. **Applying Concepts** The nerve cells in the human nervous system seldom undergo mitosis. Based on this information, explain why complete recovery from injuries to the nervous system may not occur.

33. **Formulating Hypotheses** Each type of eukaryotic organism has a characteristic number of chromosomes. Human cells, for example, generally have 46 chromosomes in their nuclei; fruit fly cells have 8 chromosomes. How might a particular type of organism be affected if this pattern were not repeated in each generation?

Focus on the BIG Idea

Science as a Way of Knowing Recall what you learned about the characteristics of life in Chapter 1. How is cell division related to one or more of those characteristics?

Writing in Science

In this chapter, you learned that cells can reproduce asexually by mitosis. In some cases, animals have the ability to reproduce asexually by a process called regeneration. If a planarian is cut into pieces, for example, it can regenerate an entire body from each piece. If large mammals were capable of regeneration, how do you think this would affect ecosystems?

Performance-Based Assessment

Demonstrate the Cell Cycle A flip-book consists of pages of sequential drawings that, when flipped, appear to move. Create a flip-book movie of the steps in the cell cycle. Be sure to show what happens to the chromosomes at each step. Exchange your flip-book with another student. Look at the other student's movie, and write a review of it.

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Standardized Test Prep

Test-Taking Tip If after reading all of the answer choices you are not sure which one is correct, eliminate the choices that you know are wrong. Then, select your answer from the remaining choices.

Directions: Choose the letter that best answers the question or completes the statement.

1. Which of the following is NOT related to a cell's ratio of surface area to volume?
   (A) cell size
   (B) rate of growth
   (C) number of nuclei
   (D) efficiency of cell's transport of oxygen
   (E) efficiency of cell's transport of nutrients
2. Which family of proteins regulates the timing of the cell cycle in eukaryotes?
   (A) chromatids
   (B) chromosomes
   (C) nutrients
   (D) DNA and RNA
   (E) cyclins
3. Which of the following is NOT a phase of mitosis?
   (A) anaphase
   (B) metaphase
   (C) telophase
   (D) prophase
   (E) interphase
4. Chromatids are attached to each other at the
   (A) nucleus.
   (B) centriole.
   (C) centromere.
   (D) cell plate.
   (E) cell membrane.
5. In the cell cycle, the period between cell divisions is called
   (A) interphase.
   (B) prophase.
   (C) G_3 phase.
   (D) telophase.
   (E) cytokinesis.

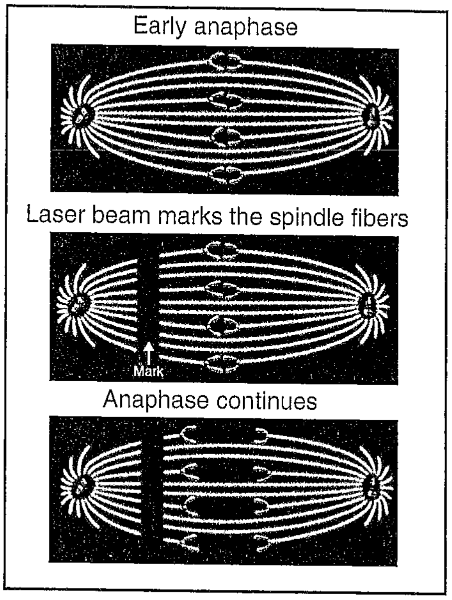
Questions 6–9 Each of the lettered choices below may refer to the following numbered statements. Select the best lettered choice.

(A) Mitosis
(B) Cell cycle
(C) Cytokinesis
(D) Cancer
(E) Interphase

6. a process in which unregulated cell division occurs
7. a process of cytoplasmic division
8. series of events that cells go through as they divide and grow
9. the division of the cell nucleus

Questions 10–12

The spindle fibers of a dividing cell were labeled with a fluorescent dye. At the beginning of anaphase, a laser beam was used to stop the dye from glowing on one side of the cell, thereby marking the fibers, as shown in the second diagram. The laser did not inhibit the normal function of the fibers.



10. This experiment tests a hypothesis about
    (A) how chromosomes migrate during cell division.
    (B) how fluorescent dyes work in the cell.
    (C) the effect of lasers on cells.
    (D) the effect of lasers on fluorescent dye.
    (E) why cells divide.
11. The diagram shows that the spindle fibers
    (A) shorten on the chromosome side of the mark.
    (B) lengthen on the chromosome side of the mark.
    (C) shorten on the centriole side of the mark.
    (D) lengthen on the centriole side of the mark.
    (E) do not change in size on either side of the mark.
12. A valid conclusion that can be drawn from this experiment is that
    (A) centrioles pull chromosomes toward the poles of the cell.
    (B) chromosomes do not migrate in the presence of dye.
    (C) lasers inhibit the migration of chromosomes.
    (D) chromosomes migrate only when treated with dye.
    (E) chromosomes travel along the fibers toward the poles of the cell.