

Root tip cells undergoing mitosis
Stained LM Magnification: 160X

Onion root tip
Stained LM Magnification: 50X

THEME FOCUS Stability and Change
Cells go through several changes as they grow and reproduce.

BIG Idea Cells go through a life cycle that includes interphase, mitosis, and cytokinesis.

Section 1 • Cellular Growth

Section 2 • Mitosis and Cytokinesis

Section 3 • Cell Cycle Regulation

Section 1

Reading Preview

Essential Questions

- Why are cells relatively small?
- What are the primary stages of the cell cycle?
- What are the stages of interphase?

Review Vocabulary

selective permeability: process in which a membrane allows some substances to pass through while keeping others out

New Vocabulary

cell cycle
interphase
mitosis
cytokinesis
chromosome
chromatin



Multilingual eGlossary

Cellular Growth

Key Idea Cells grow until they reach their size limit, then they either stop growing or divide.

Real-World Reading Link If you've ever played a doubles match in tennis, you probably felt that you and your partner could effectively cover your half of the court. However, if the court were much larger, perhaps you could no longer reach your shots. For the best game, the tennis court must be kept at regulation size. Cell size also must be limited to ensure that the needs of the cell are met.

Cell Size Limitations

Most cells are less than $100\ \mu\text{m}$ ($100 \times 10^{-6}\ \text{m}$) in diameter, which is smaller than the period at the end of this sentence. Why are most cells so small? This section investigates several factors that influence cell size.

Ratio of surface area to volume The key factor that limits the size of a cell is the ratio of its surface area to its volume. The surface area of the cell refers to the area covered by the plasma membrane. The plasma membrane is the structure through which all nutrients and waste products must pass. The volume refers to the space taken up by the inner contents of the cell, including the organelles in the cytoplasm and the nucleus.

Connection to Math To illustrate the ratio of surface area to volume, consider the small cube in **Figure 1**, which has sides of one micrometer (μm) in length. This is approximately the size of a bacterial cell. To calculate the surface area of the cube, multiply length times width times the number of sides ($1\ \mu\text{m} \times 1\ \mu\text{m} \times 6$ sides), which equals $6\ \mu\text{m}^2$. To calculate the volume of the cell, multiply length times width times height ($1\ \mu\text{m} \times 1\ \mu\text{m} \times 1\ \mu\text{m}$), which equals $1\ \mu\text{m}^3$. The ratio of surface area to volume is 6:1.

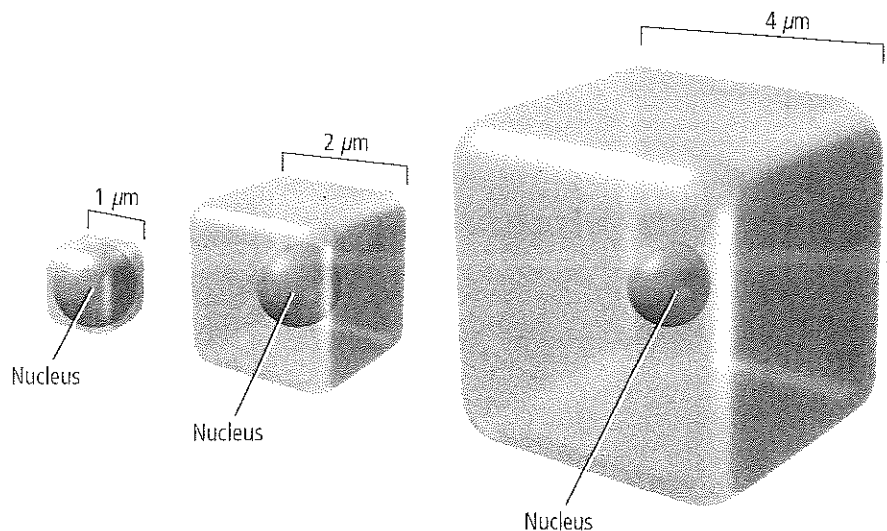



Figure 1 The ratio of surface area to volume decreases as a cell gets bigger. The smallest cube shown has a ratio of 6 ($1\ \mu\text{m} \times 1\ \mu\text{m} \times 6$ sides) to 1 ($1\ \mu\text{m} \times 1\ \mu\text{m} \times 1\ \mu\text{m}$), while the largest cube has a ratio of 96 ($4\ \mu\text{m} \times 4\ \mu\text{m} \times 6$ sides) to 64 ($4\ \mu\text{m} \times 4\ \mu\text{m} \times 4\ \mu\text{m}$), or 3:2.

If the cubic cell grows to 2 μm per side, as represented in **Figure 1**, the surface area becomes 24 μm^2 and the volume is 8 μm^3 . The ratio of surface area to volume is now 3:1, which is less than it was when the cell was smaller. If the cell continues to grow, the ratio of surface area to volume will continue to decrease, as shown by the third cube in **Figure 1**. As the cell grows, its volume increases much more rapidly than the surface area. This means that the cell might have difficulty supplying nutrients and expelling enough waste products. By remaining small, cells have a higher ratio of surface area to volume and can sustain themselves more easily.

 **Reading Check** Explain why a high ratio of surface area to volume benefits a cell.

Transport of substances Another task that can be managed more easily in a small cell than in a large cell is the movement of substances. Recall that the plasma membrane controls cellular transport because it is selectively permeable. Once inside the cell, substances move by diffusion or by motor proteins pulling them along the cytoskeleton. Diffusion over large distances is slow and inefficient because it relies on random movement of molecules and ions. Similarly, the cytoskeleton transportation network, shown in **Figure 2**, becomes less efficient for a cell if the distance to travel becomes too large. Small cell size maximizes the ability of diffusion and motor proteins to transport nutrients and waste products. Small cells maintain more efficient transport systems.

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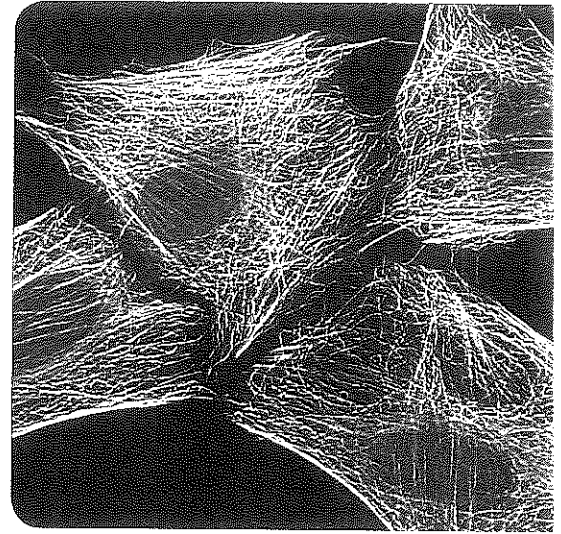


Figure 2 In order for the cytoskeleton to be an efficient transportation railway, the distances that substances have to travel within a cell must be limited.

MiniLab 1

Investigate Cell Size



Could a cell grow large enough to engulf your school? What would happen if the size of an elephant were doubled? At the organism level, an elephant cannot grow significantly larger, because its legs would not support the increase in mass. Do the same principles and limitations apply at the cellular level? Do the math!

Procedure

1. Read and complete the lab safety form.
2. Prepare a data table for surface area and volume data calculated for five hypothetical cells. Assume the cell is a cube. (Dimensions given are for one face of a cube.)
 Cell 1: 0.00002 m (the average diameter of most eukaryotic cells)
 Cell 2: 0.001 m (the diameter of a squid's giant nerve cell)
 Cell 3: 2.5 cm
 Cell 4: 30 cm
 Cell 5: 15 m
3. Calculate the surface area for each cell using the formula: length \times width \times number of sides (6).
4. Calculate the volume for each cell using the formula: length \times width \times height.

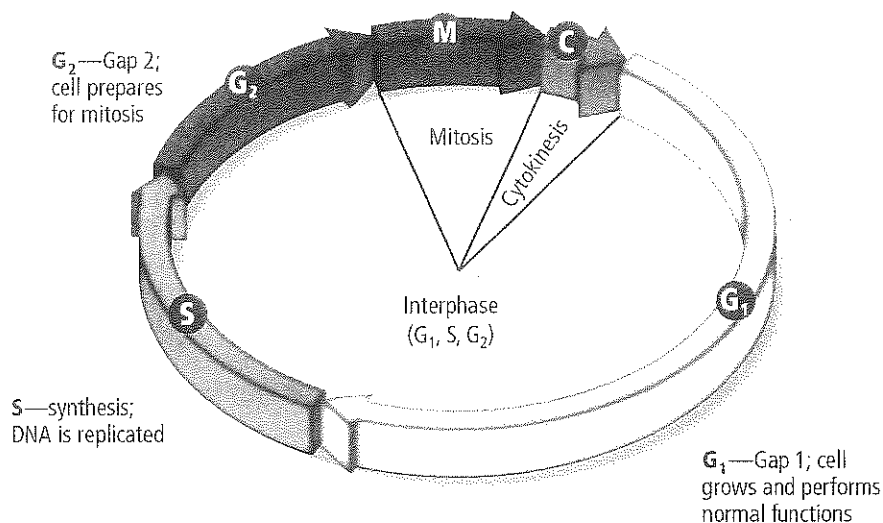
Analysis

1. **Cause and Effect** Based on your calculations, confirm why cells do not become very large.
2. **Infer** Are large organisms, such as redwood trees and elephants, large because they contain extra large cells or just more standard-sized cells? Explain.



» **Figure 3** The cell cycle involves three stages—interphase, mitosis, and cytokinesis. Interphase is divided into three substages.

Hypothesize why cytokinesis represents the smallest amount of time that a cell spends in the cell cycle.



Cellular communications The need for signaling proteins to move throughout the cell also limits cell size. In other words, cell size affects the ability of the cell to communicate instructions for cellular functions. If the cell becomes too large, it becomes almost impossible for cellular communications, many of which involve movement of substances and signals to various organelles, to take place efficiently. For example, the signals that trigger protein synthesis might not reach the ribosome fast enough for protein synthesis to occur to sustain the cell.



The Cell Cycle

Once a cell reaches its size limit, something must happen—either it will stop growing or it will divide. Most cells will eventually divide. Cell division not only prevents the cell from becoming too large, but it is also the way the cell reproduces. Cellular reproduction allows you to grow and heal certain injuries. Cells reproduce by a cycle of growing and dividing called the **cell cycle**. Each time a cell goes through one complete cycle, it becomes two cells. When the cell cycle is repeated continuously, the result is a continuous production of new cells. A general overview of the cell cycle is presented in **Figure 3**.

There are three main stages of the cell cycle. **Interphase** is the stage during which the cell grows, carries out cellular functions, and replicates, or makes copies of its DNA in preparation for the next stage of the cycle. Interphase is divided into three substages, as indicated by the segment arrows in **Figure 3**. **Mitosis** (mi TOH sus) is the stage of the cell cycle during which the cell's nucleus and nuclear material divide. Mitosis is divided into four substages. Near the end of mitosis, a process called cytokinesis begins. **Cytokinesis** (si toh kih NEE sis) is the method by which a cell's cytoplasm divides, creating a new cell. You will read more about mitosis and cytokinesis in Section 2.

The duration of the cell cycle varies, depending on the cell that is dividing. Some eukaryotic cells might complete the cycle in as few as eight minutes, while other cells might take up to one year. For most normal, actively dividing animal cells, the cell cycle takes approximately 12–24 hours. When you consider all that takes place during the cell cycle, you might find it amazing that most of your cells complete the cell cycle in about a day.

VOCABULARY

WORD ORIGIN

Cytokinesis

cyto- prefix; from the Greek word *kytos*, meaning *hollow vessel*

-kinesis from the Greek word

kinetikos, meaning *putting in motion*



The stages of interphase During interphase, the cell grows, develops into a mature, functioning cell, duplicates its DNA, and prepares for division. Interphase is divided into three stages, as shown in **Figure 3**: G_1 , S, and G_2 , also called Gap 1, synthesis, and Gap 2.

The first stage of interphase, G_1 , is the period immediately after a cell divides. During G_1 , a cell is growing, carrying out normal cell functions, and preparing to replicate DNA. Some cells, such as muscle and nerve cells, exit the cell cycle at this point and do not divide again.

The second stage of interphase, S, is the period when a cell copies its DNA in preparation for cell division. **Chromosomes** (KROH muh soh mz) are the structures that contain the genetic material that is passed from generation to generation of cells. **Chromatin** (KROH muh tun) is the relaxed form of DNA in the cell's nucleus. As shown in **Figure 4**, when a specific dye is applied to a cell in interphase, the nucleus stains with a speckled appearance. This speckled appearance is due to individual strands of chromatin that are not visible under a light microscope without the dye.

The G_2 stage follows the S stage and is the period when the cell prepares for the division of its nucleus. A protein that makes microtubules for cell division is synthesized at this time. During G_2 , the cell also takes inventory and makes sure it is ready to continue with mitosis. When these activities are completed, the cell begins the next stage of the cell cycle—mitosis.

Mitosis and cytokinesis The stages of mitosis and cytokinesis follow interphase. In mitosis, the cell's nuclear material divides and separates into opposite ends of the cell. In cytokinesis, the cell divides into two daughter cells with identical nuclei. These important stages of the cell cycle are described in Section 2.

Prokaryotic cell division The cell cycle is the method by which eukaryotic cells reproduce themselves. Prokaryotic cells, which you have learned are simpler cells, reproduce by a method called binary fission.

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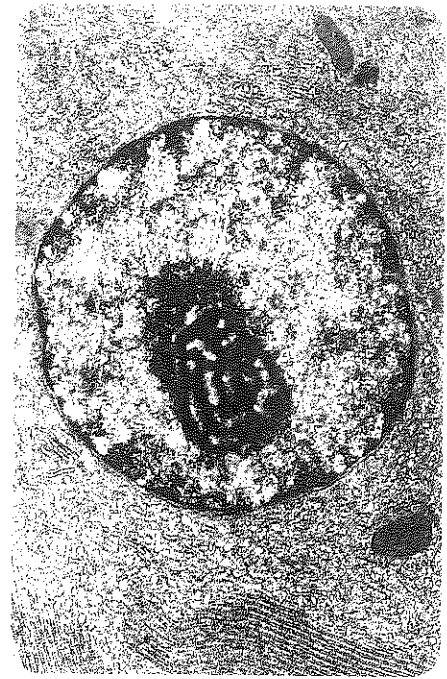


Figure 4 The grainy appearance of this nucleus from a rat liver cell is due to chromatin, the relaxed material that condenses to form chromosomes.

Section 1 Assessment

Section Summary

- The ratio of surface area to volume describes the size of the plasma membrane relative to the volume of the cell.
- Cells are limited in size, with most cells having a diameter of less than 100 μm .
- The cell cycle is the process of cellular reproduction.
- A cell spends the majority of its lifetime in interphase.

Understand Main Ideas

1. **MATH Idea** **Relate** cell size to cell functions, and explain why cell size is limited.
2. **Summarize** the primary stages of the cell cycle.
3. **Describe** what happens to DNA during the S stage of interphase.
4. **Create** a diagram of the stages of the cell cycle and describe what happens in each.

Think Critically

5. **Hypothesize** what the result would be if a large cell managed to divide, despite the fact that it had grown beyond an optimum size.

MATH in Biology

6. If a cube representing a cell is 100 μm on a side, calculate the surface area-to-volume ratio, and explain why this is or is not a good size for a cell.



Section 2

Reading Preview

Essential Questions

- What are the events of each stage of mitosis?
- What is the process of cytokinesis?

Review Vocabulary

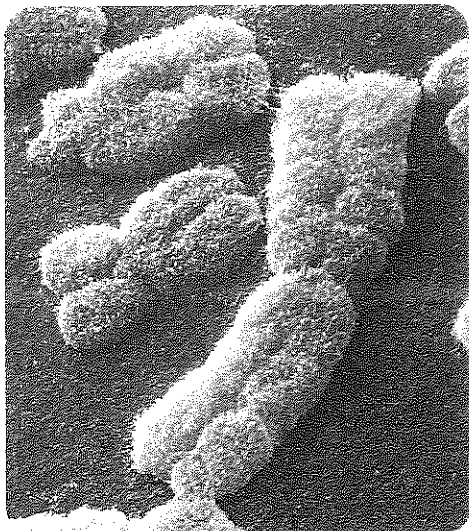
life cycle: the sequence of growth and development stages that an organism goes through during its life

New Vocabulary

prophase
sister chromatid
centromere
spindle apparatus
metaphase
anaphase
telophase

 Multilingual eGlossary

Figure 5 Chromosomes in prophase are actually sister chromatids that are attached at the centromere.



Color-Enhanced SEM magnification: 6875x

Mitosis and Cytokinesis

MAIN Idea Eukaryotic cells reproduce by mitosis, the process of nuclear division, and cytokinesis, the process of cytoplasm division.

Real-World Reading Link Many familiar events are cyclic in nature. The course of a day, the changing of seasons year after year, and the passing of comets in space are some examples of cyclic events. Cells also have a cycle of growth and reproduction.

Mitosis

You learned in the last section that cells cycle through interphase, mitosis, and cytokinesis. During mitosis, the cell's replicated genetic material separates and the cell prepares to split into two cells. The key activity of mitosis is the accurate separation of the cell's replicated DNA. This enables the cell's genetic information to pass into the new cells intact, resulting in two daughter cells that are genetically identical. In multicellular organisms, the process of mitosis increases the number of cells as a young organism grows to its adult size. Organisms also use mitosis to replace damaged cells. Recall the last time you were accidentally cut. The body's process of healing the cut involves generating new skin cells. These new cells are produced by your existing skin cells. Under the scab, the existing skin cells divided by mitosis and cytokinesis to create new skin cells that filled the gap in the skin caused by the injury.

The Stages of Mitosis

Like interphase, mitosis is divided into stages: prophase, metaphase, anaphase, and telophase.

Prophase The first stage and longest phase of mitosis is called **prophase**. In this stage, the cell's chromatin tightens, or condenses, into chromosomes. In prophase, the chromosomes are shaped like an X, as shown in **Figure 5**. At this point, each chromosome is a single structure that contains the genetic material that was replicated in interphase. Each half of this X is called a sister chromatid. **Sister chromatids** are structures that contain identical copies of DNA. The structure at the center of the chromosome where the sister chromatids are attached is called the **centromere**. This structure is important because it ensures that a complete copy of the replicated DNA will become part of the daughter cells at the end of the cell cycle. Locate prophase in the cell cycle illustrated in **Figure 6**, and note the position of the sister chromatids. As you continue to read about the stages of mitosis, refer back to **Figure 6** to follow the chromatids through the cell cycle.

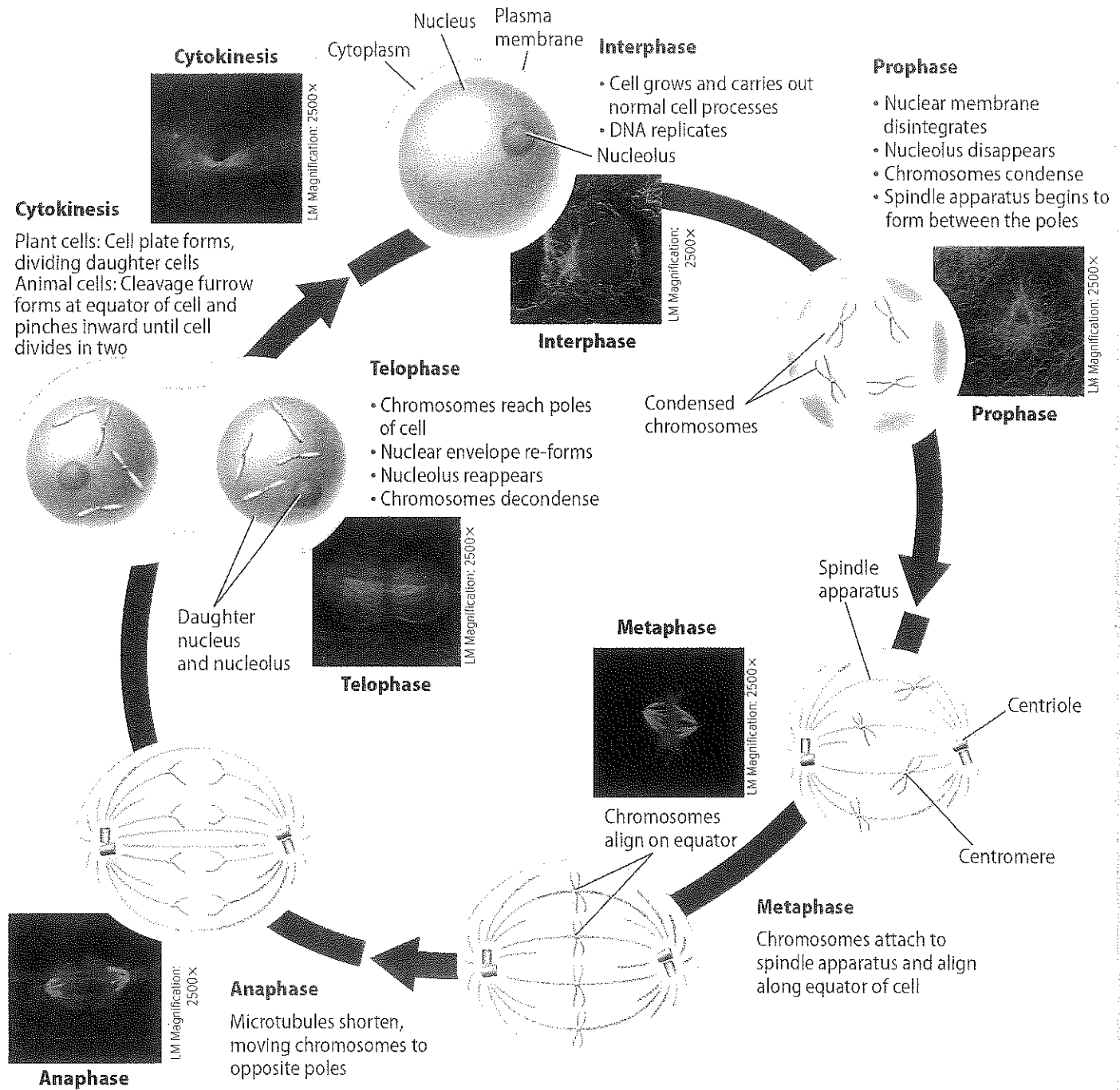


Reading Check **Compare** the key activity of interphase with the key activity of mitosis.

Visualizing the Cell Cycle

Figure 6

The cell cycle begins with interphase. Mitosis follows, occurring in four stages—prophase, metaphase, anaphase, and telophase. Mitosis is followed by cytokinesis, then the cell cycle repeats with each new cell.

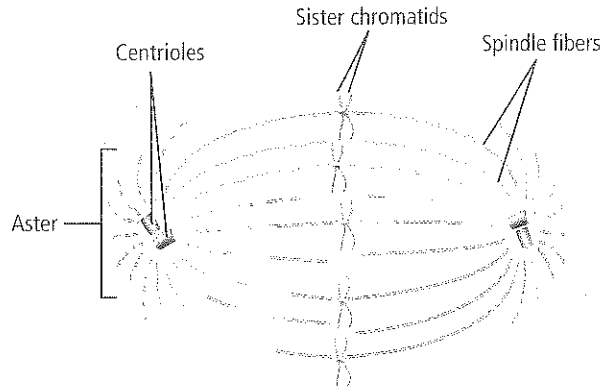


Animation

LM Magnification: 100×



❖ **Figure 7** In animal cells, the spindle apparatus is made of spindle fibers, centrioles, and aster fibers.



As prophase continues, the nucleolus seems to disappear. Microtubule structures called spindle fibers form in the cytoplasm. In animal cells and most protist cells, another pair of microtubule structures called centrioles migrates to the ends, or poles, of the cell. Coming out of the centrioles are yet another type of microtubule called aster fibers, which have a starlike appearance. The whole structure, including the spindle fibers, centrioles, and aster fibers, is called the **spindle apparatus** and is shown in **Figure 7**. The spindle apparatus is important in moving and organizing the chromosomes before cell division. Centrioles are not part of the spindle apparatus in plant cells.

FOLDABLES

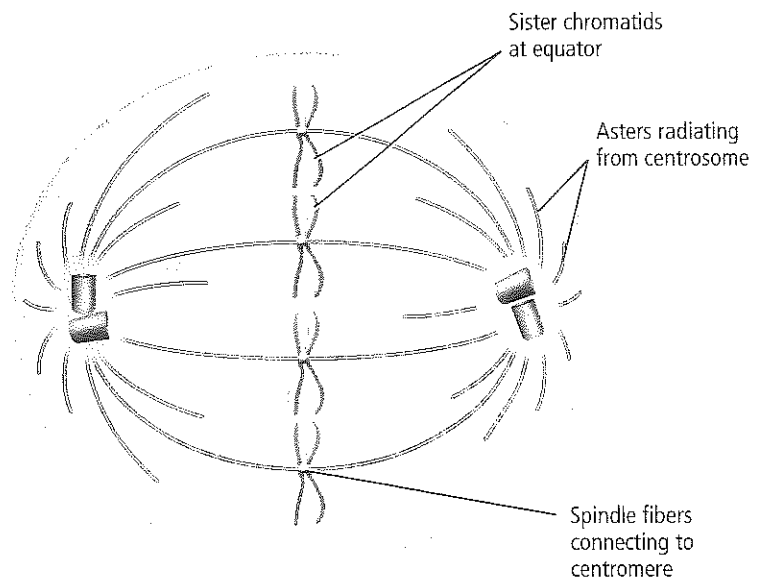
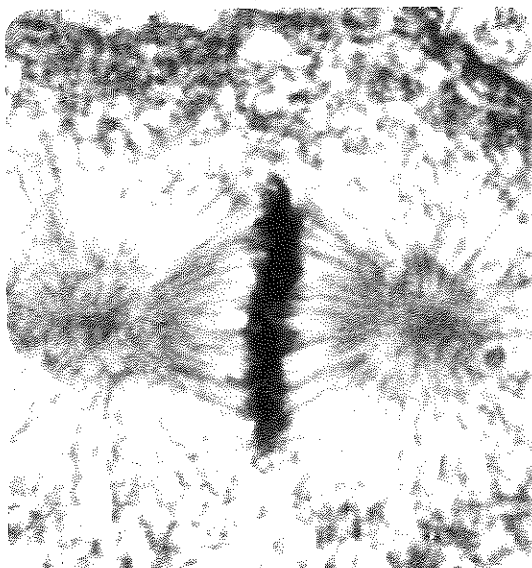
Incorporate information from this section into your Foldable.

Near the end of prophase, the nuclear envelope seems to disappear. The spindle fibers attach to the sister chromatids of each chromosome on both sides of the centromere and then attach to opposite poles of the cell. This arrangement ensures that each new cell receives one complete copy of the DNA.

❖ **Figure 8** In metaphase, the chromosomes align along the equator of the cell. *Infer why the chromosomes align along the equator.*

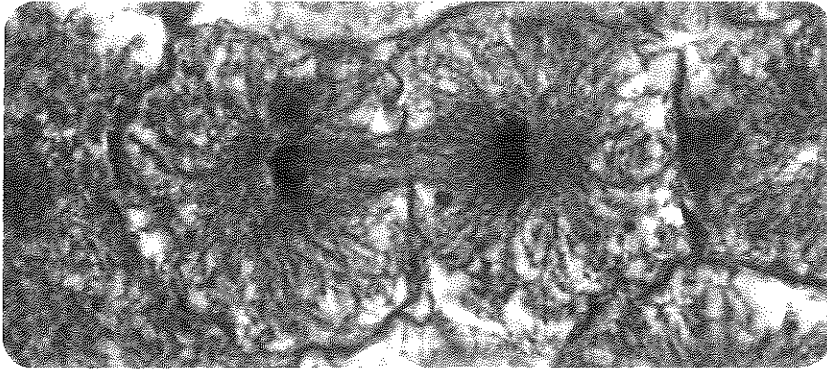
Metaphase During the second stage of mitosis, **metaphase**, the sister chromatids are pulled by motor proteins along the spindle apparatus toward the center of the cell and they line up in the middle, or equator, of the cell, as shown in **Figure 8**. Metaphase is one of the shortest stages of mitosis, but when completed successfully, it ensures that the new cells have accurate copies of the chromosomes.

Light Micrograph Magnification: unavailable



(1) Jennifer C. Waters/Photo Researchers; (2) Science Source





Anaphase The chromatids are pulled apart during **anaphase**, the third stage of mitosis. In anaphase, the microtubules of the spindle apparatus begin to shorten. This shortening pulls at the centromere of each sister chromatid, causing the sister chromatids to separate into two identical chromosomes. All of the sister chromatids separate simultaneously, although the exact mechanism that controls this is unknown. At the end of anaphase, the microtubules, with the help of motor proteins, move the chromosomes toward the poles of the cell.

Telophase The last stage of mitosis is called telophase. **Telophase** is the stage of mitosis during which the chromosomes arrive at the poles of the cell and begin to relax, or decondense. As shown in **Figure 9**, two new nuclear membranes begin to form and the nucleoli reappear. The spindle apparatus disassembles and some of the microtubules are recycled by the cell to build various parts of the cytoskeleton. Although the four stages of mitosis are now complete and the nuclear material is divided, the process of cell division is not yet complete.

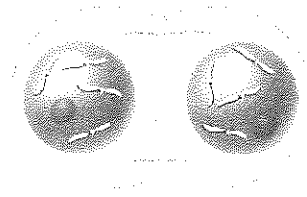


Figure 9 By the end of telophase, the cell has completed the work of duplicating the genetic material and dividing it into two "packages," but the cell has not completely divided.

APPLYING PRACTICES

Develop and Use Models Go to the resources tab in Connected to find the Applying Practices worksheet *Mitosis and Cellular Differentiation*.

DATA ANALYSIS LAB 1

Based on Real Data*

Predict the Results

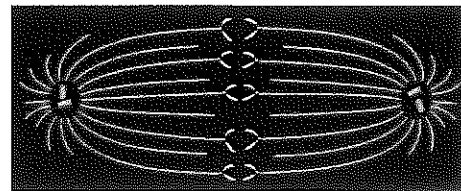
What happens to the microtubules? Scientists performed experiments tracking chromosomes along microtubules during mitosis. They hypothesized that the microtubules are broken down, releasing microtubule subunits as the chromosomes are moved toward the poles of the cell. The microtubules were labeled with a yellow fluorescent dye, and using a laser, the microtubules were marked midway between the poles and the chromosomes by eliminating the fluorescence in the targeting region as shown in the diagram.

Think Critically

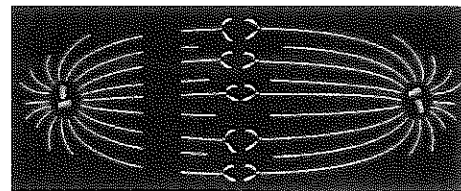
1. **Explain** the purpose of the fluorescent dye.
2. **Predict** how the cell might appear later in anaphase by drawing a diagram.

*Data obtained from: Maddox, P., et al. 2003. Direct observation of microtubule dynamics at kinetochores in extract spindles: Implications for spindle mechanics. *The Journal of Cell Biology* 162: 377-382. Maddox, et al. 2004. Controlled ablations of microtubules using picosecond laser. *Biophysics Journal* 87: 4203-4212.

Data and Observations

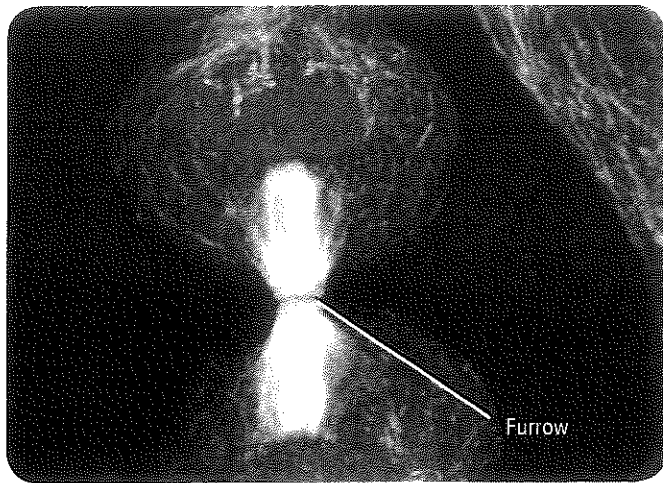


Fluorescent-labeled microtubules



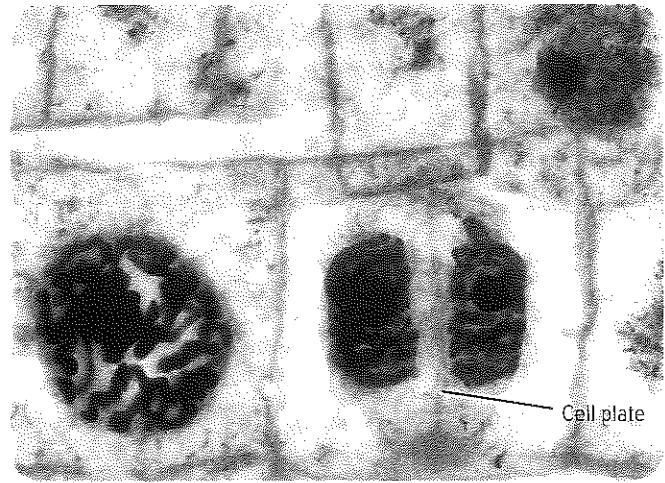
Laser-marked microtubules



**Animal cell****Figure 10**

Left: In animal cells, cytokinesis begins with a furrow that pinches the cell and eventually splits the two cells apart.

Right: Plant cells build a cell plate that divides the cell into the two daughter cells.

**Plant cells**

Cytokinesis

Toward the end of mitosis, the cell begins another process called cytokinesis that will divide the cytoplasm. This results in two cells, each with identical nuclei. In animal cells, cytokinesis is accomplished by using microfilaments to constrict, or pinch, the cytoplasm, as shown in **Figure 10**. The area where constriction occurs is called the furrow.

Recall that plant cells have a rigid cell wall covering their plasma membrane. Instead of pinching in half, a new structure called a cell plate forms between the two daughter nuclei, as illustrated in **Figure 10**. Cell walls then form on either side of the cell plate. Once this new wall is complete, there are two genetically identical cells.

Prokaryotic cells, which divide by binary fission, finish cell division in a different way. When prokaryotic DNA is duplicated, both copies attach to the plasma membrane. As the plasma membrane grows, the attached DNA molecules are pulled apart. The cell completes fission, producing two new prokaryotic cells.

Section 2 Assessment

Section Summary

- Mitosis is the process by which the duplicated DNA is divided.
- The stages of mitosis include prophase, metaphase, anaphase, and telophase.
- Cytokinesis is the process of cytoplasm division that results in genetically identical daughter cells.

Understand Main Ideas

1. **MAIN Idea** Explain why mitosis alone does not produce daughter cells.
2. **Describe** the events of each stage of mitosis.
3. **Diagram** and label a chromosome in prophase.
4. **Identify** the stage of mitosis in which a cell spends the most time.
5. **Contrast** cytokinesis in a plant cell and an animal cell.

Think Critically

6. **Hypothesize** what might happen if a drug that stopped microtubule movement but did not affect cytokinesis was applied to a cell.

MATH in Biology

7. If a plant cell completes the cell cycle in 24 hours, how many cells will be produced in a week?



Section 3

Reading Preview

Essential Questions


- What is the role of cyclin proteins in controlling the cell cycle?
- How does cancer relate to the cell cycle?
- What is the role of apoptosis?
- What are the two types of stem cells and what are their potential uses?

Review Vocabulary

nucleotide: subunit that makes up DNA and RNA molecules

New Vocabulary

cyclin
cyclin-dependent kinase
cancer
carcinogen
apoptosis
stem cell

 Multilingual eGlossary

Cell Cycle Regulation

 **Read** The normal cell cycle is regulated by cyclin proteins.

Real-World Reading Link No matter how many new homes a builder builds, even if building the same design, the crew always relies on blueprint instructions. Similarly, cells have specific instructions for completing the cell cycle.

Normal Cell Cycle

The timing and rate of cell division are important to the health of an organism. The rate of cell division varies depending on the type of cell. A mechanism involving proteins and enzymes controls the cell cycle.

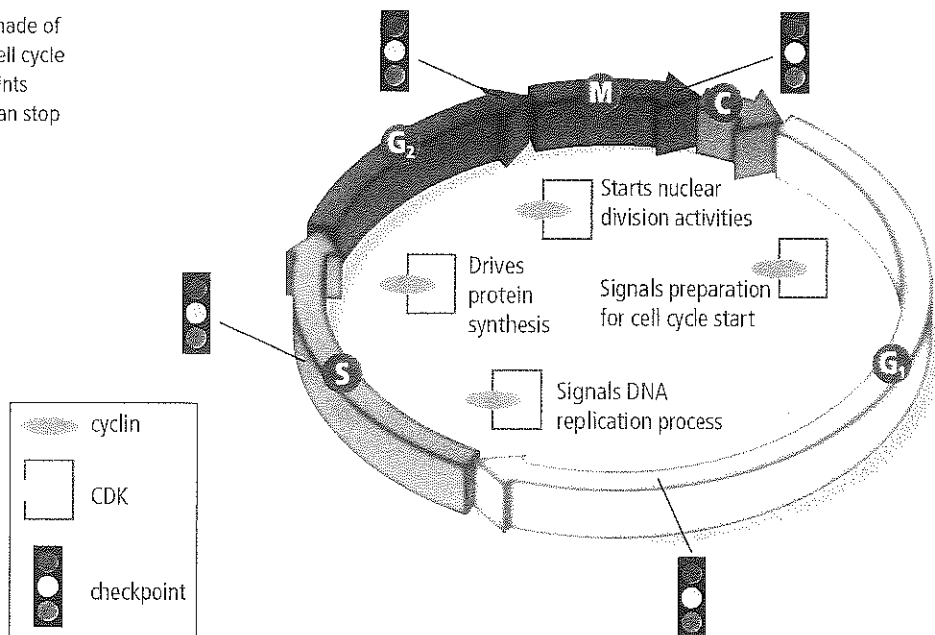
The role of cyclins To start most cars, it takes a key turning in the ignition to signal the engine to start. Similarly, the cell cycle in eukaryotic cells is driven by a combination of two substances that signal the cellular reproduction processes. Proteins called **cyclins** bind to enzymes called **cyclin-dependent kinases (CDKs)** in the stages of interphase and mitosis to start the various activities that take place in the cell cycle. Different cyclin/CDK combinations control different activities at different stages in the cell cycle.

Figure 11 illustrates where some of the important combinations are active.

In the G_1 stage of interphase, the combination of cyclin with CDK signals the start of the cell cycle. Different cyclin/CDK combinations signal other activities, including DNA replication, protein synthesis, and nuclear division throughout the cell cycle. The same cyclin/CDK combination also signals the end of the cell cycle.

Figure 11 Signaling molecules made of a cyclin bound to a CDK kick off the cell cycle and drive it through mitosis. Checkpoints monitor the cell cycle for errors and can stop the cycle if an error occurs.

 Personal Tutor



CAREERS IN BIOLOGY

Pharmaceutical QC Technician

Just as the cell cycle has built-in quality control checkpoints, so do biological product manufacturing processes. A QC (quality control) technician in a pharmaceutical manufacturing company uses various science and math skills to monitor processes and ensure product quality.



What's BIOLOGY Got To Do With It?



Virtual Lab

Quality control checkpoints Recall the process of starting a car. Many manufacturers use a unique microchip in the key to ensure that only a specific key will start each car. This is a checkpoint against theft. The cell cycle also has built-in checkpoints that monitor the cycle and can stop it if something goes wrong. For example, a checkpoint near the end of the G_1 stage monitors for DNA damage and can stop the cycle before entering the S stage of interphase. There are other quality control checkpoints during the S stage and after DNA replication in the G_2 stage. Spindle checkpoints also have been identified in mitosis. If a failure of the spindle fibers is detected, the cycle can be stopped before cytokinesis. **Figure 11** shows the location of key checkpoints in the cell cycle.

Abnormal Cell Cycle: Cancer

Connection Although the cell cycle has a system of quality control checkpoints, it is a complex process that sometimes fails. When cells do not respond to the normal cell cycle control mechanisms, a condition called cancer can result. **Cancer** is the uncontrolled growth and division of cells—a failure in the regulation of the cell cycle. When unchecked, cancer cells can kill an organism by crowding out normal cells, resulting in the loss of tissue function. Cancer cells spend less time in interphase than do normal cells, which means cancer cells grow and divide unrestrained as long as they are supplied with essential nutrients. **Figure 12** shows how cancer cells can intrude on normal cells.

Causes of cancer Cancer does not just occur in a weak organism. In fact, cancer occurs in many healthy, active, and young organisms. The changes that occur in the regulation of cell growth and division of cancer cells are due to mutations or changes in the segments of DNA that control the production of proteins, including proteins that regulate the cell cycle. Often, the genetic change or damage that occurs is repaired by various repair systems. But if the repair systems fail, cancer can result. Various environmental factors can affect the occurrence of cancer cells. Substances and agents that are known to cause cancer are called **carcinogens** (kar SIH nuh junz).

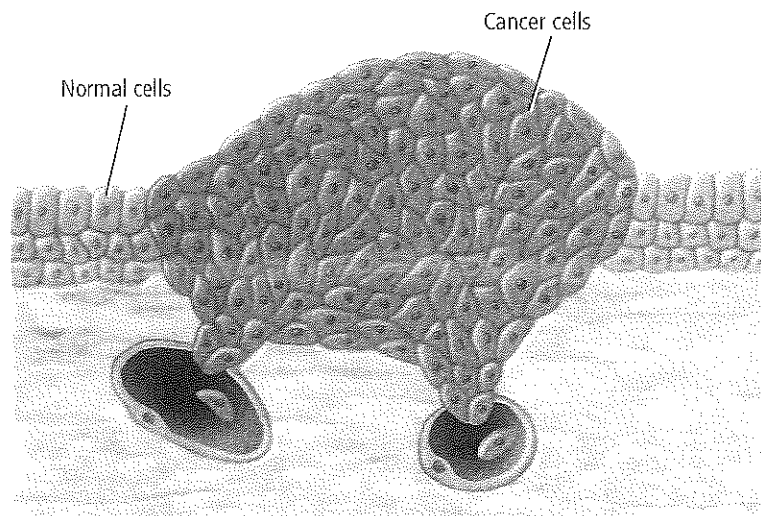



Figure 12 Cancer cells often have an abnormal, irregular shape compared to normal cells. In this image some cancer cells are entering vessels, which might carry them to another part of the body. This is one way cancer can spread from one body part to another.



Although not all cancers can be prevented, avoiding known carcinogens can help reduce the risk of cancer. A governmental agency called the Food and Drug Administration (FDA) works to make sure that the things you eat and drink are safe. The FDA requires labels and warnings for products that might be carcinogens. Industrial laws help protect people from exposure to cancer-causing chemicals in the workplace. Avoiding tobacco of all kinds, even secondhand smoke and smokeless tobacco, can reduce the risk of cancer.

Some radiation, such as ultraviolet radiation from the Sun, is impossible to avoid completely. There is a connection between the amount of ultraviolet radiation to which a person is exposed and the risk of developing skin cancer. Therefore, sunscreen is recommended for everyone who is exposed to the Sun. Other forms of radiation, such as X-rays, are used for medical purposes, such as to view a broken bone or to check for cavities in teeth. To protect against exposure, you might have worn a heavy lead apron when an X-ray was taken.

 **Reading Check** Identify carcinogens to which you are regularly exposed.

Cancer genetics More than one change in DNA is required to change an abnormal cell into a cancer cell. Over time, there might be many changes in DNA. This might explain why the risk of cancer increases with age. An individual who inherits one or more changes from a parent is at a higher risk for developing cancer than someone who does not inherit these changes.



Launch Lab

Review Based on what you've read about the abnormal cell cycle and its results, how would you now answer the analysis questions?

VOCABULARY

SCIENCE USAGE / COMMON USAGE

Inheritance

Science usage: the passing of genetic traits from parent to offspring via DNA

A person's body structure and facial appearance are the result of genetic inheritance.

Common usage: assets acquired from a deceased person that can be given to surviving family members

The house was Jim's inheritance from his uncle.

Mini Lab 2

Compare Sunscreens



MiniLab

Do sunscreens really block sunlight? Sunscreens contain a variety of different compounds that absorb UVB from sunlight. UVB is linked to mutations in DNA that can lead to skin cancer. Find out how effective at blocking sunlight various sunscreens are.

Procedure

1. Read and complete the lab safety form.
2. Choose one of the **sunscreen products** provided by your teacher. Record the active ingredients and the Sun protection factor (SPF) on a data sheet.
3. Obtain **two sheets of plastic wrap**. On one sheet use a **permanent marker** to draw two widely spaced circles. Place a drop of sunscreen in the middle of one circle and a drop of **zinc oxide** in the middle of the other.
4. Lay the second sheet on top of both circles. Spread the drops by pressing with a **book**.
5. Take a covered piece of **Sun-sensitive paper** and your two pieces of plastic wrap to a sunny area. Quickly uncover the paper, lay the two pieces of plastic wrap on top, and place in the sunlight.
6. After the paper is fully exposed (1–5 minutes), remove it from the sunlight and develop according to instructions.

Analysis

1. **Think Critically** Why did you compare the sunscreens to zinc oxide?
2. **Draw Conclusions** After examining the developed Sun-sensitive papers from your class, which sunscreens do you think would be most likely to prevent DNA mutations?



VOCABULARY

ACADEMIC VOCABULARY

Mature

to have reached full natural growth or development

After mitosis, the two new cells must mature before they divide.

Apoptosis

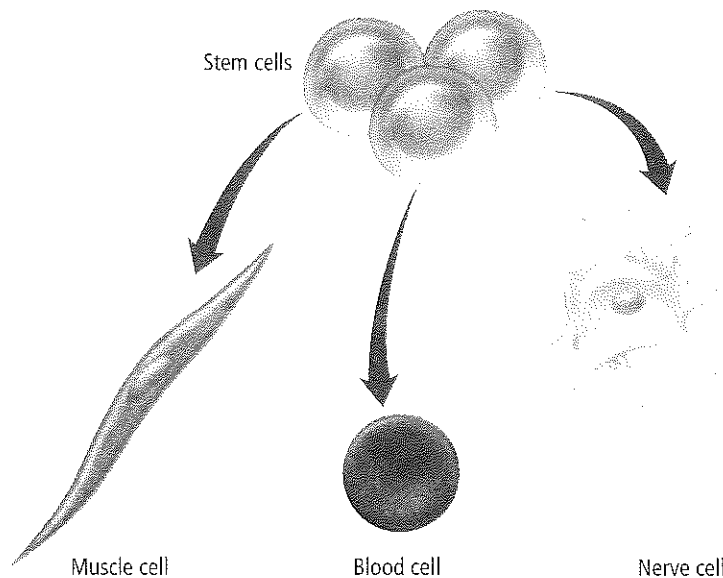
Not every cell is destined to survive. Some cells go through a process called **apoptosis** (a pup TOH sus), or programmed cell death. Cells going through apoptosis actually shrink and shrivel in a controlled process. All animal cells appear to have a “death program” that can be activated.

One example of apoptosis occurs during the development of the human hand and foot. When the hands and feet begin to develop, cells occupy the spaces between the fingers and toes. Normally, this tissue undergoes apoptosis, with the cells shriveling and dying at the appropriate time so that the webbing is not present in the mature organism. An example of apoptosis in plants is the localized death of cells that results in leaves falling from trees during autumn. Apoptosis also occurs in cells that are damaged beyond repair, including cells with DNA damage that could lead to cancer. Apoptosis can help to protect organisms from developing cancerous growths.

Stem Cells

The majority of cells in a multicellular organism are designed for a specialized function. Some cells might be part of your skin, and other cells might be part of your heart. In 1998, scientists discovered a way to isolate a unique type of cell in humans called the stem cell. **Stem cells** are unspecialized cells that can develop into specialized cells under the right conditions, as illustrated in **Figure 13**. Stem cells can remain in an organism for many years while undergoing cell division. There are two basic types of stem cells: embryonic stem cells and adult stem cells.

Embryonic stem cells After a sperm fertilizes an egg, the resulting mass of cells divides repeatedly until there are about 100–150 cells. These cells have not become specialized and are called embryonic stem cells. If separated, each of these cells has the capability of developing into a wide variety of specialized cells. If the embryo continues to divide, the cells specialize into various tissues, organs, and organ systems. Embryonic stem cell research is controversial because of ethical concerns about the source of the cells.



• **Figure 13** Because stem cells are not locked into becoming one particular type of cell, they might be the key to curing many medical conditions and genetic defects.

Explain how stem cells could be used to cure nerve damage.



• **Figure 14** Research with adult stem cells has led to advances in treatments for numerous injuries and diseases.

Adult stem cells The second type of stem cells—adult stem cells—is found in various tissues in the body and might be used to maintain and repair the same kind of tissue in which they are found. The term “adult stem cells” might be somewhat misleading because even a newborn has adult stem cells. Like embryonic stem cells, certain kinds of adult stem cells also might be able to develop into different kinds of cells, providing new treatments for many diseases and conditions. In 1999, researchers at Harvard Medical School used nervous system stem cells to restore lost brain tissue in mice. In 2008, researchers used adult stem cells along with an enzyme called PKA to create new bone tissue for repair in mice. Research with adult stem cells, like that shown in **Figure 14**, is much less controversial because the adult stem cells can be obtained with the consent of their donors.

Section 3 Assessment

Section Summary

- The cell cycle of eukaryotic cells is regulated by cyclins.
- Checkpoints occur during most of the stages of the cell cycle to ensure that the cell divides accurately.
- Cancer is the uncontrolled growth and division of cells.
- Apoptosis is a programmed cell death.
- Stem cells are unspecialized cells that can develop into specialized cells with the proper signals.

Understand Main Ideas

1. **WRITE** **Idea** Describe how cyclins control the cell cycle.
2. **Explain** how the cancer cell cycle is different from a normal cell cycle.
3. **Identify** three carcinogens.
4. **Contrast** apoptosis and cancer.
5. **Describe** a possible application for stem cells.
6. **Explain** the difference between embryonic stem cells and adult stem cells.

Think Critically

7. **Hypothesize** what might happen if apoptosis did not occur in cells that have significant DNA damage.

WRITING IN Biology

8. Write a public service announcement about carcinogens. Choose a specific type of cancer, and write about the carcinogens linked to it.



Biology & Society

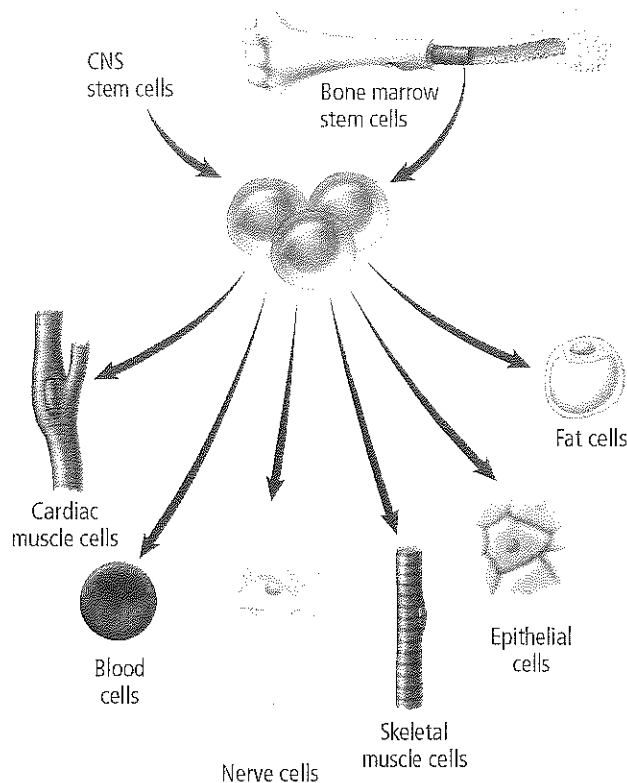
Stem Cells: Paralysis Cured?

A race car driver is paralyzed in a crash. A teen is paralyzed after diving into shallow water. Until recently, these individuals would have little hope of regaining the full use of their bodies, but new research on adult stem cells shows promise for reversing paralysis.

How can stem cells be used? Scientists are trying to find ways to grow stem cells in cell cultures and manipulate them to generate specific cell types. For example, stem cells might be used to repair cardiac tissue after a heart attack, to restore vision in diseased or injured eyes, to treat diseases such as diabetes, or to repair spinal cells to reverse paralysis. Current stem cell research in Ecuador involves bone marrow cells (BMCs). BMCs are adult stem cells being used to grow blood vessels. Re-establishing blood flow and oxygen to tissues aids in the healing process and provides therapy options for patients.

Stem cells and paralysis In Portugal, Dr. Carlos Lima and his team of researchers found that tissue taken from the nasal cavity is a rich source of adult stem cells. These stem cells become nerve cells when transplanted into the site of a spinal cord injury. The new nerve cells replace the cells that were damaged.

More than forty patients with paralysis due to accidents have undergone the Portuguese procedure. All patients have regained some sensation in paralyzed body areas. Most have regained some motor control. With intensive physical therapy, about ten percent of the patients now can walk with the aid of supportive devices, such as walkers and braces. This is promising news to the many individuals facing illnesses or injuries that have robbed them of the full use of their bodies.



Stem cells from bone marrow or the central nervous system can be manipulated to generate many cell types that can be transplanted to treat illness or repair damage.

Stem cells and the future Scientists are eager to do the research necessary to make adult stem cell treatments a regular part of health care. Paralysis might not have to be permanent; stem cells could provide the cure.

WRITING in Biology

Pamphlet Create an illustrated pamphlet depicting the benefits of adult stem cell research. Research adult stem cells in order to include the research methodology, treatment, examples, cell physiology, and history of adult stem cell research.

BIOLAB

DOES SUNLIGHT AFFECT MITOSIS IN YEAST?

Background: Ultraviolet (UV) radiation is a component of sunlight that can damage DNA and interrupt the cell cycle.

Question: *Can sunscreens prevent damage to UV-sensitive yeast?*

Materials

sterile pipettes (10)
aluminum foil
test-tube rack
sterile spreaders or sterile cotton swabs (10)
dilution of UV-sensitive yeast
yeast extract dextrose (YED) agar plates (10)
sunscreens with various amounts of SPF

Safety Precautions



Procedure

1. Read and complete the lab safety form.
2. Obtain a test tube containing a diluted broth culture of the UV-sensitive yeast.
3. Formulate a hypothesis, then choose a sunscreen and predict how it will affect the yeast when exposed to sunlight.
4. Label ten YED agar plates with your group name. Label two plates as control. The control plates will not be placed in the sunlight. Label four of the experimental plates as “no sunscreen” and four as “sunscreen.”
5. Spread a 0.1 mL sample of the yeast dilution on all ten YED agar plates. Wrap the control plates in foil and give them to your teacher for incubation.
6. With direction from your teacher, decide how long to expose each of the experimental plates and label each plate accordingly. Prepare a table in which to collect your data.

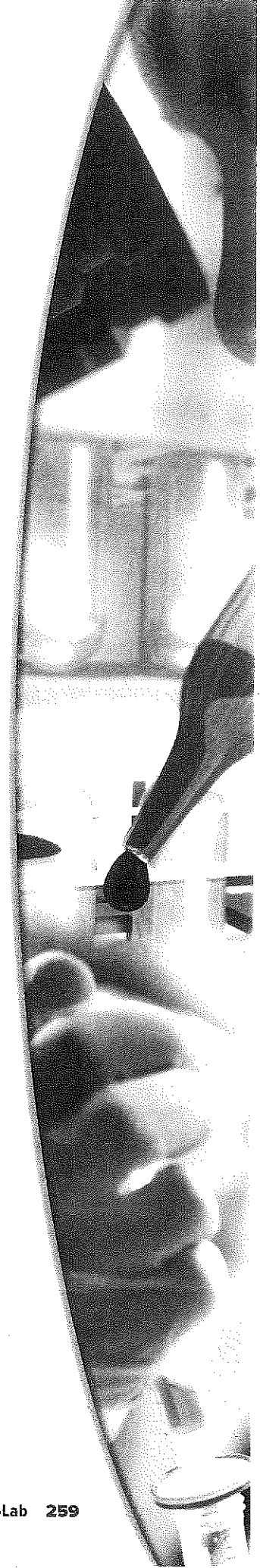
7. Wrap the “no sunscreen” plates in foil. Apply sunscreen to the lids of the four sunscreen plates and wrap them in foil.
8. Remove only enough aluminum foil from each of the experimental plates to expose the dish lids. Expose the plates for the planned times. Re-cover the plates after exposure and give them to your teacher for incubation.
9. After incubation, count and record the number of yeast colonies on each plate.
10. **Cleanup and Disposal** Wash and return all reusable materials. Dispose of the YED plates as instructed by your teacher. Disinfect your work area. Wash your hands thoroughly with soap and water.

Analyze and Conclude

1. **Estimate** Assume that each yeast colony on a YED plate grew from one yeast cell in the dilution. Use the number of yeast colonies on your control plate to determine the percent of yeast that survived on each exposed plate.
2. **Graph Data** Draw a graph with the percent survival on the y -axis and the exposure time on the x -axis. Use a different color to graph the data from the plates with and without sunscreen.
3. **Evaluate** Was your hypothesis supported by your data? Explain.
4. **Error Analysis** Describe several possible sources of error.

APPLY YOUR SKILL

Brainstorm Work with classmates to research and locate information and ideas about how UV-sensitive yeast could be used as a biological monitor to detect increases in the amounts of UV light reaching Earth's surface.



Chapter 9 Study Guide

THEME FOCUS Stability and Change Stem cells undergo many changes to differentiate into one of many types of specialized cells.

BIG Idea Cells go through a life cycle that includes interphase, mitosis, and cytokinesis.

Section 1 Cellular Growth

cell cycle (p. 246)
interphase (p. 246)
mitosis (p. 246)
cytokinesis (p. 246)
chromosome (p. 247)
chromatin (p. 247)

BIG Idea Cells grow until they reach their size limit, then they either stop growing or divide.

- The ratio of surface area to volume describes the size of the plasma membrane relative to the volume of the cell.
- Cells are limited in size, with most cells having a diameter of less than 100 μm .
- The cell cycle is the process of cellular reproduction.
- A cell spends the majority of its lifetime in interphase.

Section 2 Mitosis and Cytokinesis

prophase (p. 248)
sister chromatid (p. 248)
centromere (p. 248)
spindle apparatus (p. 250)
metaphase (p. 250)
anaphase (p. 251)
telophase (p. 251)

BIG Idea Eukaryotic cells reproduce by mitosis, the process of nuclear division, and cytokinesis, the process of cytoplasm division.

- Mitosis is the process by which the duplicated DNA is divided.
- The stages of mitosis include prophase, metaphase, anaphase, and telophase.
- Cytokinesis is the process of cytoplasm division that results in genetically identical daughter cells.

Section 3 Cell Cycle Regulation

cyclin (p. 253)
cyclin-dependent kinase (p. 253)
cancer (p. 254)
carcinogen (p. 254)
apoptosis (p. 256)
stem cell (p. 256)

BIG Idea The normal cell cycle is regulated by cyclin proteins.

- The cell cycle of eukaryotic cells is regulated by cyclins.
- Checkpoints occur during most of the stages of the cell cycle to ensure that the cell divides accurately.
- Cancer is the uncontrolled growth and division of cells.
- Apoptosis is a programmed cell death.
- Stem cells are unspecialized cells that can develop into specialized cells with the proper signals.



Section 1

Vocabulary Review

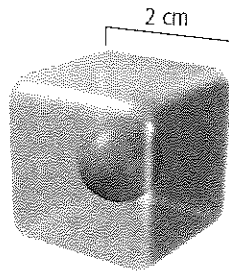
Match the correct vocabulary term from the Study Guide page to the following definitions.

- the period in which the cell is not dividing
- the process of nuclear division
- the sequence of events in the life of a eukaryotic cell

Understand Main Ideas

- Which is a reason why cells remain small?
 - Large cells have difficulty diffusing nutrients rapidly enough.
 - As cells grow, their ratio of surface area to volume decreases.
 - Transportation of wastes becomes a problem for large cells.
 - All of the above.

Use the hypothetical cell shown below to answer question 5.



- What is the ratio of surface area to volume?

A. 2:1	C. 4:1
B. 3:1	D. 6:1
- Of the surface area-to-volume ratio, what does the surface area represent in a cell?
 - nucleus
 - plasma membrane
 - mitochondria
 - cytoplasm
- Which describes the activities of a cell that include cellular growth and cell division?

A. chromatin	C. mitosis
B. cytoplasm	D. cell cycle

- As a cell's volume increases, what happens to the proportional amount of surface area?
 - increases
 - decreases
 - stays the same
 - reaches its limit

Constructed Response

- Write an Idea** Why are cellular transport and cellular communication factors that limit cell size?
- Short Answer** Summarize the relationship between surface area and volume as a cell grows.
- Short Answer** What types of activities are going on in a cell during interphase?

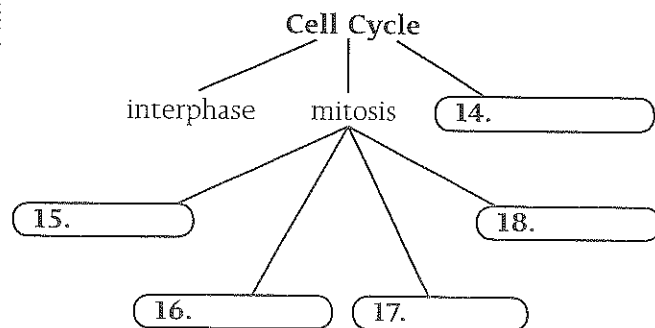
Think Critically

- Criticize** this statement: Interphase is a "resting period" for the cell before it begins mitosis.
- Explain** the relationship of DNA, a chromosome, and chromatin.

Section 2

Vocabulary Review

Complete the concept map using vocabulary terms from the Study Guide page.



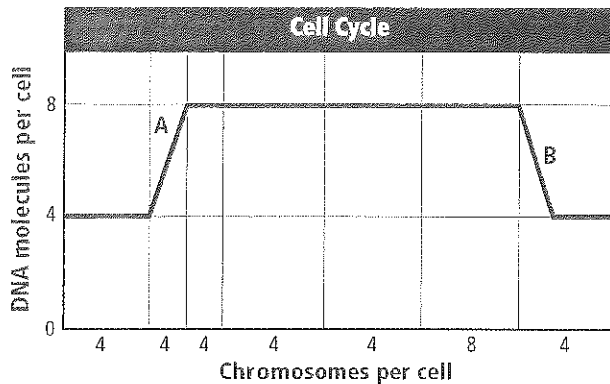
Understand Main Ideas

- Starting with one cell that underwent six divisions, how many cells would result?

A. 13	C. 48
B. 32	D. 64



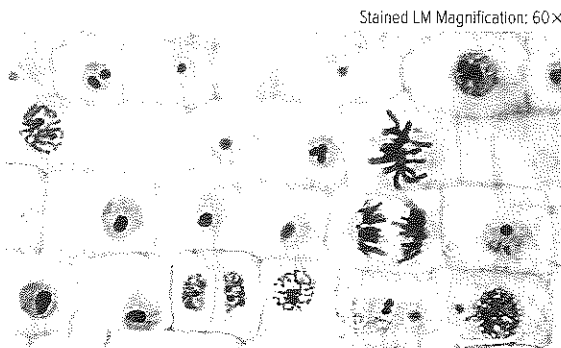
The following graph shows a cell over the course of its cell cycle. Use this graph to answer questions 20 and 21.



20. What stage occurred in the area labeled A?
- prophase
 - G_1 stage
 - S stage
 - G_2 stage
21. What process occurred in the area labeled B?
- interphase
 - cytokinesis
 - mitosis
 - metabolism
22. The cancer drug vinblastine interferes with synthesis of microtubules. In mitosis, this would interfere with what?
- spindle formation
 - DNA replication
 - carbohydrate synthesis
 - disappearance of the nuclear envelope

Constructed Response

23. **Think Idea** During the cell cycle, when would a chromosome consist of two identical sister chromatids?
24. **Short Answer** In the following image of a section of onion root tip, identify a cell in each of the following stages: interphase, prophase, metaphase, anaphase, and telophase.



25. **Short Answer** Describe the events that occur in telophase.

Think Critically

26. **Evaluate** While looking through a microscope, you see a cell plate forming. This cell is most likely what type of cell?
27. **MATH in Biology** A biologist examines a series of cells and counts 90 cells in interphase, 13 cells in prophase, 12 cells in metaphase, 3 cells in anaphase, and 2 cells in telophase. If a complete cycle for this type of cell requires 24 hours, what is the average duration of mitosis?

Section 3

Vocabulary Review

The sentences below include term(s) that have been used incorrectly. Replace the incorrect term(s) with vocabulary terms from the Study Guide page to make the sentences true.

28. Stem cells undergo uncontrolled, unrestrained growth and division because their genes have been changed.
29. Cancer is a cell response to DNA damage that results in cell death.
30. Cyclins are substances that cause cancer.

Understand Main Ideas

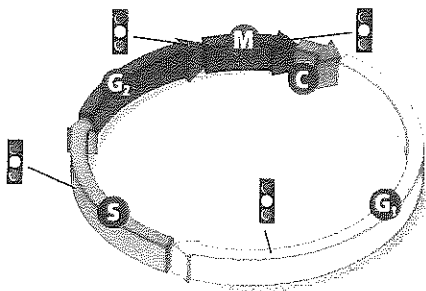
31. What is the role of cyclins in a cell?
- to control the movement of microtubules
 - to signal for the cell to divide
 - to stimulate the breakdown of the nuclear membrane
 - to cause the nucleolus to disappear
32. What substances form the cyclin-cyclin dependent kinase combinations that control the stages in the cell cycle?
- fats and proteins
 - carbohydrates and proteins
 - proteins and enzymes
 - fats and enzymes



33. Which is a characteristic of cancer cells?
- controlled cell division
 - contain multiple genetic changes
 - cytokinesis stage is skipped
 - cell cyclins function normally
34. Which describes apoptosis?
- occurs in all cells
 - is a programmed cell death
 - disrupts the normal development of an organism
 - is a response to hormones
35. Why have some stem cell researchers experienced roadblocks in their studies?
- Stem cells cannot be found.
 - There are ethical concerns about obtaining stem cells.
 - There are no known uses for stem cells.
 - Stem cells do not become specialized cells.

Constructed Response

Refer to the diagram to answer question 36.



36. **THEME FOCUS Stability and Change** Explain the relationship between cancer cells and the cell cycle.
37. **Short Answer** Distinguish between mitosis and apoptosis.

Think Critically

38. **Describe** how stem cells might be used to help a patient who has a damaged spinal cord.
39. **IDEA** Explain how the lack of cyclins would affect the cell cycle.
40. **Apply** Hundreds of millions of dollars are spent annually in the U.S. on the research and treatment of cancer, with much less being spent on cancer prevention. Compose a plan that would increase cancer prevention knowledge.

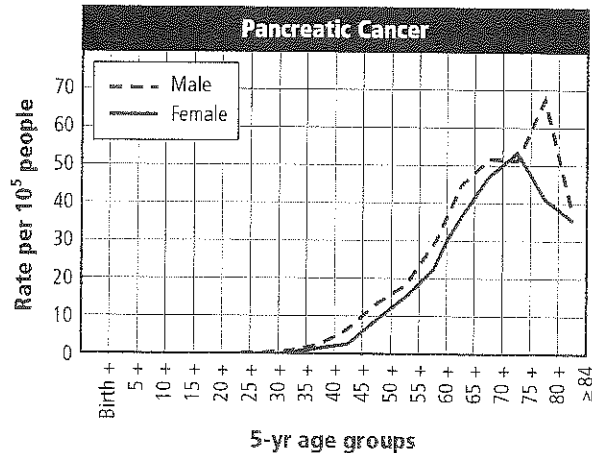
Summative Assessment

41. **BIOL (Idea)** Besides reproduction, what factors cause cells to complete the cycle of interphase, mitosis, and cytokinesis?
42. **WRITING IN Biology** Write a skit using props and people to demonstrate mitosis.
43. Research chemicals that are carcinogens and write about how these chemicals can damage DNA.

B Document-Based Questions

Dr. Chang and co-workers evaluated the risk of pancreatic cancer by studying its occurrence in a population group. Their data included age at diagnosis. The graph below shows cancer diagnosis rates for African-American men and women.

Data obtained from: Chang, K. J. et al. 2005. Risk of pancreatic adenocarcinoma. *Cancer* 103: 349-357.



44. Summarize the relationship between the occurrence of cancer and age.
45. Considering what you know about cancer and the cell cycle, explain why incidences of cancer increase with age.
46. Compare the ages of men and women who are diagnosed with cancer.
47. At what age does diagnosis of pancreatic cancer decline?

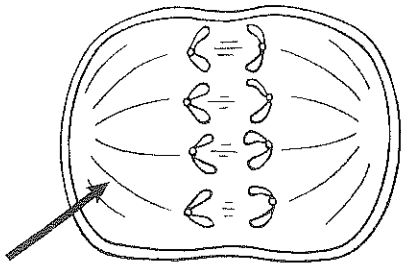
Standardized Test Practice

Cumulative

Multiple Choice

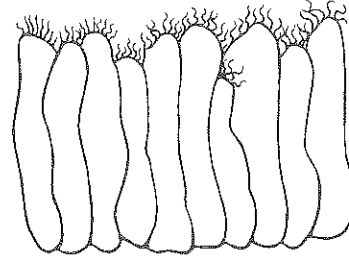
1. Carbon (C) has four electrons in its outer energy level, and fluorine (F) has seven. Which compound would carbon and fluorine most likely form?
- A. CF_2
 - B. CF_3
 - C. CF_4
 - D. CF_5

Use the diagram below to answer questions 2 and 3.



2. Which stage of mitosis is shown in this diagram?
- A. anaphase
 - B. interphase
 - C. metaphase
 - D. telophase
3. To which structure does the arrow in the diagram point?
- A. centromere
 - B. chromosome
 - C. nucleolus
 - D. spindle
4. Which stage of photosynthesis requires water to complete the chemical reaction?
- A. action of ATP synthase on ADP
 - B. conversion of GAP molecules into RuBP
 - C. conversion of $NADP^+$ to NADPH
 - D. transfer of chemical energy to form GAP molecules
5. Which carbon-containing compound is the product of glycolysis?
- A. acetyl CoA
 - B. glucose
 - C. lactic acid
 - D. pyruvate

Use the diagram below to answer question 6.

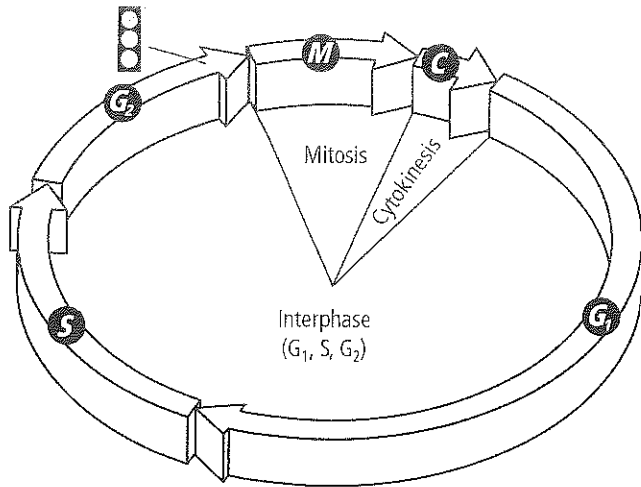


6. What are the structures projecting from the cells in the diagram?
- A. cilia
 - B. flagella
 - C. microfilaments
 - D. villi
7. Which cellular process stores energy?
- A. the breaking of lipid chains
 - B. the conversion of ADP to ATP
 - C. the synthesization of proteins from RNA codons
 - D. the transportation of ions across the membrane
8. Which contributes to the selective permeability of cell membranes?
- A. carbohydrates
 - B. ions
 - C. minerals
 - D. proteins
9. If data from repeated experiments support a hypothesis, which would happen next?
- A. A conclusion would be established.
 - B. The data would become a law.
 - C. The hypothesis would be rejected.
 - D. The hypothesis would be revised.
10. Which type of heterotroph is a mouse?
- A. carnivore
 - B. detritivore
 - C. herbivore
 - D. omnivore



Short Answer

Use the diagram below to answer questions 11-13.



- In the past, interphase often was called the “resting” phase of the cell cycle. Explain why this is inaccurate.
- Explain what the cell does at the checkpoint indicated by the stoplight in the diagram.
- Use the diagram to compare the relative rates at which mitosis and cytokinesis occur.
- Hypothesize how an organism could be both a heterotroph and an autotroph.
- Suppose you had ink, pebbles, and table salt. Describe what kind of mixture each one of these would make if mixed with water. Explain your answers.
- Name two enzymes involved in photosynthesis, and describe their roles.
- Infer how the ratio of surface area to volume changes as a cell grows larger.

NEED EXTRA HELP?

If You Missed Question . . .

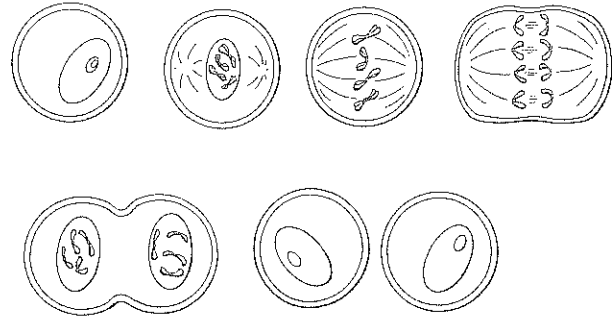
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

Review Section . . .

6.1 9.2 9.2 8.2 8.3 7.3 8.1 7.2 1.3 2.1 9.1 9.1 8.2 8.1 6.3 8.2 9.1 9.2 9.2 7.3

Extended Response

Use the diagram below to answer questions 18 and 19.



- Analyze the diagram and describe the importance of the spindle fibers to chromatids during prophase.
- Describe the function of the centromere and predict what might happen if cells did NOT have centromeres.

Essay Question

The same organelles are found in many different types of cells in an animal’s body. However, there are differences in the number of organelles present, depending on the function of the different cells. For instance, the cells that require a great amount of energy to carry out their work would contain more mitochondria.

Using the information in the paragraph above, answer the following question in essay format.

- How do you think two types of animal cells would differ in terms of the kinds of organelles they contain? Write a hypothesis about the cellular differences between two types of animal cells and then design an experiment to test your hypothesis.

