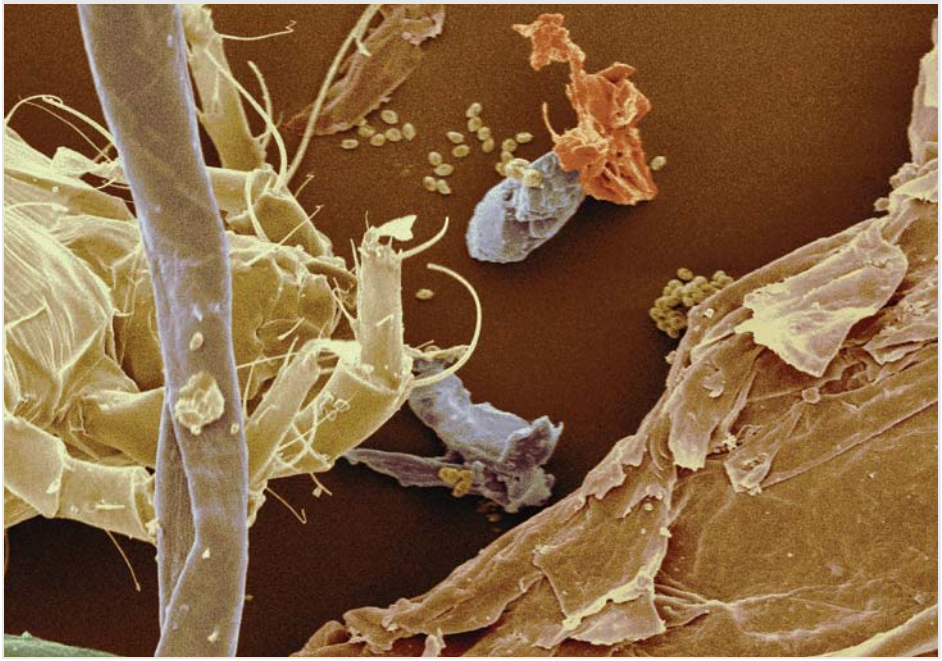
UNIT 5

Cells: Stability and Change

These living cells are in various stages of growth and division.

FIGURE 1: This scanning electron micrograph of household dust shows skin flakes, fabric fibers, part of a dead dust mite, and fungal spores.



Your skin comprises roughly 16 percent of your body weight. Skin cells are easily shed, and as a result, we lose thousands of skin cells per hour. In fact, we lose so many skin cells that they can be found in the dust in our homes.

Predict How do you think multicellular organisms such as humans replace lost cells?

DRIVING QUESTIONS

As you move through the unit, gather evidence to help you answer the following questions. In your Evidence Notebook, record what you already know about these topics and any questions you have about them.

1. How do organisms balance the growth and division of their cells?
2. How do organisms replace lost or damaged cells?
3. Do all cells grow and divide in the same way? At the same rate?
4. How do organisms with many cell types develop from a single cell?

UNIT PROJECT

Cauliflower Cloning

Some plants, such as cauliflower, can regenerate whole plants from small pieces of material. How does the plant make new cells and structures? Culture your own cauliflower plant from a small cutting, and observe the growth over time. What processes play roles in the formation of a new plant?

Go online to download the Unit Project Worksheet to help plan your project.

5.1

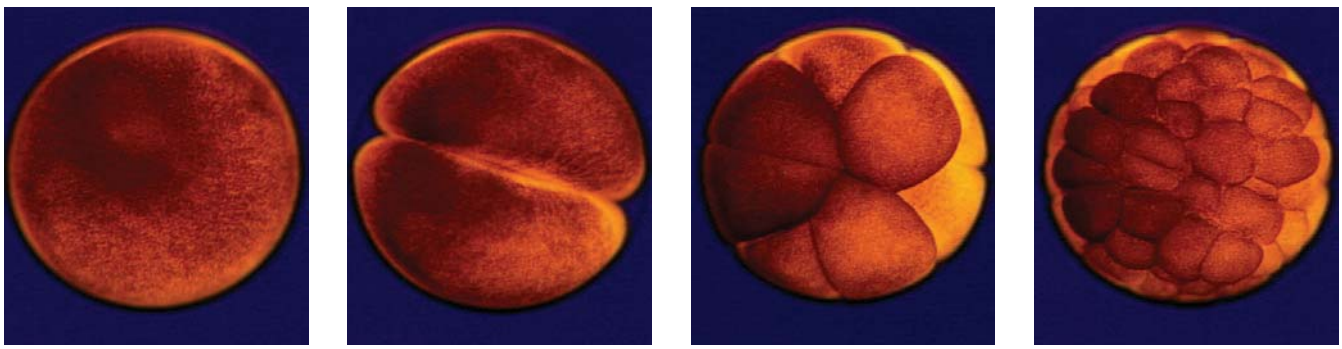
The Cell Cycle

This frog began as a single cell that repeatedly divided to form this multicellular organism.

CAN YOU EXPLAIN IT?

FIGURE 1: A frog develops from a single cell. This cell divides into two cells, each of which divide again and again, trillions of times. As this pattern continues, many different cells develop.

Explore Online



Gather Evidence
As you explore the lesson, gather evidence for how the cell cycle is related to the growth and maintenance of organisms.

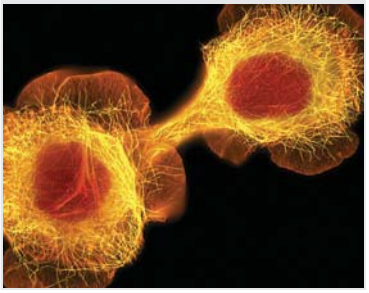
All cells come from existing cells. This is easily observed in single-celled organisms, such as bacteria, some of which can reproduce in as little as 20 minutes. Multicellular organisms, such as a frog, begin as a single cell that repeatedly divides to form a complex multicellular organism. Some organisms reproduce asexually, making genetically identical clones of themselves. Other organisms, like humans, reproduce sexually. A sexually reproducing organism begins as a fertilized egg. A sperm cell and an egg cell fuse to form a cell, called a zygote. The zygote divides trillions of times to produce a complex, multicellular organism.

Predict Why aren't all organisms made of just one cell? Why do cells divide, instead of simply growing larger?

Overview of the Cell Cycle

Living systems go through cycles of stable conditions and changing conditions. For example, when conditions in your outside environment change, homeostatic mechanisms in your body help restore internal stability. Cells also cycle between phases of stability and change. Some cells stay in a relatively steady state, without dividing, for long periods of time. Other cells are constantly dividing.

FIGURE 2: A dividing cell

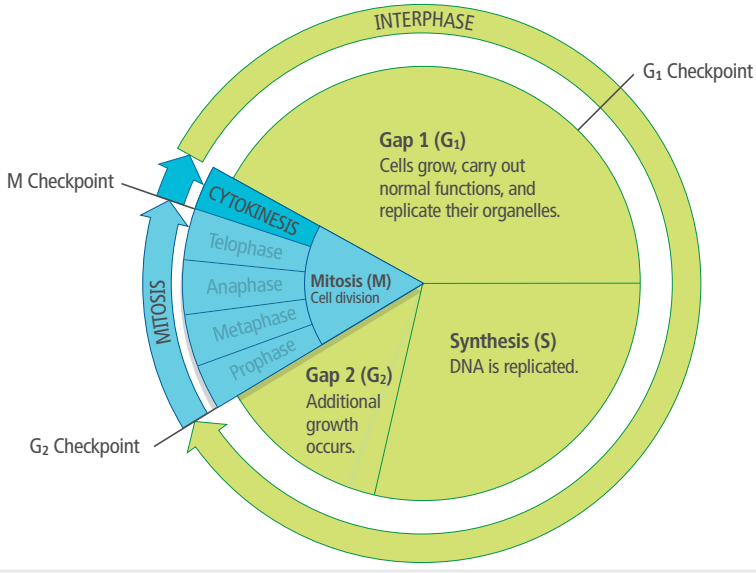


Stages of the Cell Cycle

The life cycle of organisms involves birth, growth and development, reproduction, and eventually death. A cell also has a life cycle, and cell division is only one part of that cycle. The cell cycle is the regular pattern of growth, DNA duplication, and cell division that occurs in eukaryotic cells, or cells with nuclei. This pattern can be divided into stages that get their names from the earliest studies of cell division, when scientists' observations were limited by the microscopes of the time.

Because these scientists were unable to observe activity in cells that were not actively dividing, they separated the cycle into two parts: a resting phase and a dividing phase. The resting stage was named interphase, and the division phase was named mitosis. Mitosis includes a final step for complete cell division called cytokinesis.

FIGURE 3: The Cell Cycle



Over time, scientists developed techniques and tools that allowed them to detect the copying of DNA (DNA synthesis). As a result, the description of the cell cycle was revised to include the DNA synthesis stage. At the time, they were still unable to observe activity between the stages of synthesis and mitosis, so the periods between these two stages were labeled gap 1 (G_1) and gap 2 (G_2). Eventually scientists learned that cells in interphase undergo critical growth and preparation for cell division while they carry out normal cellular functions.

Predict Describe a specific situation in which an organism's cells would need to divide.

Analyze Why is it important that DNA is copied before the cell divides?

Checkpoints in the cell cycle keep cells from moving to the next stage before certain conditions are met. During G_1, the cell must pass a critical checkpoint before it can proceed to the synthesis stage. This ensures that DNA is relatively undamaged and can be properly replicated. This checkpoint also allows other cells to signal the cell when more cell division is needed. G_2 has its own critical checkpoint. Everything must be in order—adequate cell size, DNA correctly replicated—before the cell goes through mitosis and division.

Collaborate If a cell has damaged DNA, what do you think happens during the G_2 checkpoint?

Rates of Cell Division

All cells in your body undergo cell division, but the rate at which they divide is linked to your body's need for that type of cell. In human cells, the S, G_2, and M stages together usually take about 12 hours. The length of the G_1 stage differs the most from cell type to cell type. The rate of cell division is greater in embryos and children than it is in adults. Children have a shorter cell cycle, and many of their organs are still developing. But the rate of cell division also varies within different tissues of the adult body. For example, the internal lining of the digestive tract receives a lot of wear and tear. The cells of the lining also encounter toxins that enter the body through the digestive tract. As a result, cells that line the stomach and intestine are replaced every few days. In contrast, cells that make up the rest of the intestine (mainly smooth muscle) and many of the internal organs, such as lungs, kidneys, and liver, divide only occasionally, in response to cell injury or death.

FIGURE 4: Different cells divide at different rates.

Cell Type	Approximate Life Span
Skin cell	2–3 weeks
Red blood cell	4 months
Liver cell	10–18 months
Intestine–internal lining	4–5 days
Intestine–muscle and other tissues	16 years

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

Analyze Why does a skin cell need to divide more frequently than a liver cell?

G Zero (G_0) Stage

Not all cells need to divide regularly. Cells that divide rarely are thought to enter a gap phase called G_0. These cells continue to carry out everyday functions, but they do not undergo any of the processes necessary to prepare for division. Some cells, such as neurons, may remain in G_0 permanently. Other cells enter this stage temporarily until there is a need for them to divide. One such cell is a lymphocyte, which is a type of white blood cell that helps fight infections. Lymphocytes can remain dormant for years until they recognize an invading organism. Once the invading organism binds to a lymphocyte receptor, the lymphocyte goes through a series of rapid cell divisions to help fight infection.

Explain Make a claim for how the cell cycle relates to the growth and maintenance of organisms. Discuss the stages of the cell cycle, mechanisms that regulate it, and how this cycle is related to the growth and maintenance of organisms.

Factors Affecting Cell Growth

Many factors influence cell growth and division, including cell size. A typical animal cell only grows to a size of 10–20 micrometers. Cell size is often expressed as a comparison of two quantities: surface area and volume. A cell's surface area-to-volume ratio is the relationship between the surface area of a cell's membrane and the inner volume of a cell.

Problem Solving

Calculating Cell Size

A ratio is a comparison of two numbers. For example, suppose there are 25 students in a class—10 boys and 15 girls. The ratio of boys to girls is 10 to 15. We can express this ratio in one of three ways:

$$10 \text{ to } 15 \qquad 10{:}15 \qquad \frac{10}{15}$$

A ratio can be reduced, just like any other fraction. Ratios are reduced by determining the lowest common denominator. In the example above, the greatest common factor is 5.

$$\frac{10}{15} = \frac{2}{3} = 2{:}3$$

SAMPLE PROBLEM

Study this sample problem for Cell A.

FIGURE 5: Cells are measured by their surface area and volume.

Calculate the surface area-to-volume ratio for Cell A.

1. Surface area = length × width × number of sides = 1 × 1 × 6 = 6.
2. Volume = length × width × height = 1 × 1 × 1 = 1.
3. Surface area-to-volume ratio = 6:1.

SOLVE

Calculate the surface area-to-volume ratio for Cell B and Cell C.

1. Calculate the surface area of Cell B and Cell C.
2. Calculate the volume of Cell B and Cell C.
3. Calculate the surface area-to-volume ratio for Cell B and Cell C.

Explain Describe the pattern you observe in the surface area-to-volume ratios as the cell gets larger.

Explore Online

Hands-On Lab

Modeling Cell Surface Area-to-Volume Ratio Use model cells to investigate how a cell's size affects its ability to transport materials across the membrane and maintain homeostasis.

Cell Size

Recall that oxygen, nutrients, and wastes move across the cell membrane, or the surface of the cell. Some diffuse passively across the membrane, while others are transported actively via specialized proteins. No matter how materials move across the membrane, they must be transported in adequate amounts and with adequate speed to maintain homeostasis. If there is not enough surface area for materials to cross into and out of the cell, the cell may not be able to absorb materials or expel wastes effectively. To maintain a suitable cell size, growth and division must be coordinated.

Explain Make a claim for why cells must divide, rather than grow larger. Explain how surface area and volume, as well as transport across the cell membrane, are related to cell size and homeostasis.

Regulating Cell Division

Like other cellular processes, the cell cycle must be regulated. The cell cycle is regulated by both internal and external factors that work together to control when and how often a cell divides. Internal factors come from inside the cell and include several types of molecules found in the cytoplasm. External factors come from outside the cell, either from nearby cells or from another part of the organism's body.

An external factor that regulates the cell cycle can be either a physical signal or a chemical signal. One example of a physical signal—cell-to-cell contact—can be observed in a single layer culture of mammalian cells. Individual cells will divide in these cultures until they touch other cells. At this point, they stop dividing. Scientists are not yet sure what causes this to happen. One hypothesis is that receptors on the surfaces of neighboring cells bind to each other, causing the cell's cytoskeletons to form structures that can block growth signals. Many cells also release chemical signals that can stimulate the growth of other cells. For example, growth factors are a broad group of proteins that stimulate cell division.

When external factors bind to their receptors on a cell's surface, they can trigger internal factors that affect the cell cycle. Two well-studied kinds of internal factors are kinases and cyclins. A kinase is an enzyme that, when activated, transfers a phosphate group from ATP to a specific target molecule. This action typically increases the energy of the target molecule, changes its shape, or both. Your cells have many types of kinases, and they are almost always present in the cell. Those kinases that help control the cell cycle are activated by cyclins. Cyclins are a group of proteins that are rapidly made and destroyed at certain points in the cell cycle. These two factors help a cell advance to different stages of the cell cycle when they bind to each other. This cyclin-kinase interaction plays an important role in cell cycle checkpoints, ensuring that cells start and stop dividing at appropriate times.

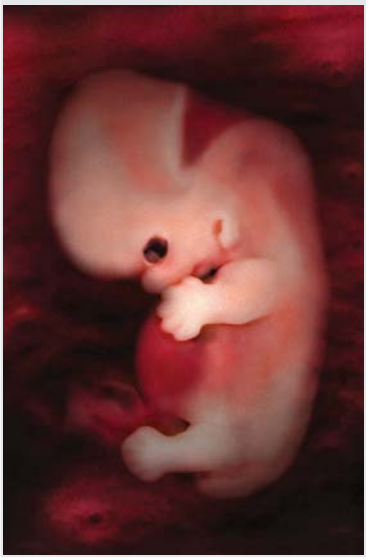
Model Create a graphic organizer to describe the different factors that influence cell division. Include information related to the cell cycle, rates of cell division, cell size, and internal and external factors.

Apoptosis

Some cells are programmed to die at a predetermined time in their life cycle or after a certain number of cell divisions. Programmed cell death is known as apoptosis, and it occurs when internal or external signals activate genes that help produce self-destructive enzymes. Apoptosis may occur in cells with damaged DNA or in cells that are harmful to, or simply no longer needed by, the body. Normally immune system cells ignore other cells in the body, but some immune cells are specialized to recognize apoptotic cells. These cells very tidily gobble up the apoptotic cell and recycle its chemical parts for use in building other molecules. Apoptosis is also an important process in normal embryological development in animals, including humans.

Collaborate Human embryos have webbed digits (fingers and toes) early in their development. The cells between the digits undergo apoptosis during later stages of development. With a partner, draw a model to show how apoptosis leads to changes in the structure of digits during later stages of development.

FIGURE 6: In early stages of development, human embryos have webbing between their fingers and toes.

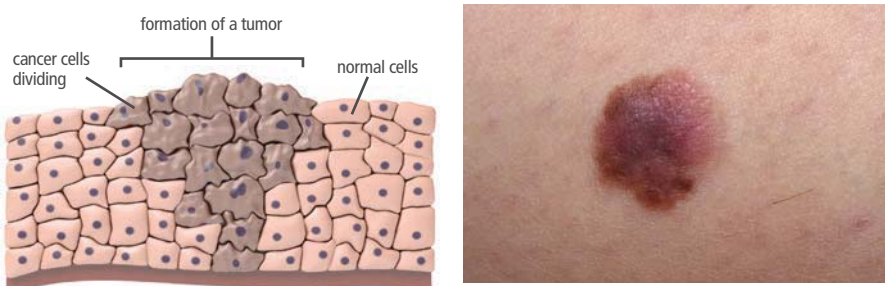


Cancer

Cancer is the common name for a class of diseases characterized by uncontrolled cell division. It arises when regulation of the cell cycle is disrupted. Because they do not respond to factors regulating growth, cancer cells divide more often than healthy cells. This results in the formation of disorganized clumps of cells called tumors. Some tumors can be removed successfully if they remain localized. However, some cells break away and are carried to other places in the body where they create new tumors in a process called metastasis. Cancer cells are hazardous because they do not perform normal cell functions. For example, in the lungs, cancer cells do not develop into healthy lung tissue and do not properly carry out gas exchange.

Cells become cancerous when mutations occur in sections of DNA that code for regulatory factors. Some mutations are caused by radiation or chemical exposure while others are inherited. Substances that promote or produce cancerous growth are called carcinogens. These include tobacco smoke and certain air pollutants. Some cancers are inherited when the abnormal gene that causes the cancer is passed on from generation to generation.

FIGURE 7: Normal animal cells respond to external factors and stop dividing when they touch each other. Cancer cells fail to respond to these factors. The cancerous growth shown here is a form of skin cancer called melanoma.



Explain Describe the differences in the normal cells and the cancerous cells shown in Figure 7.

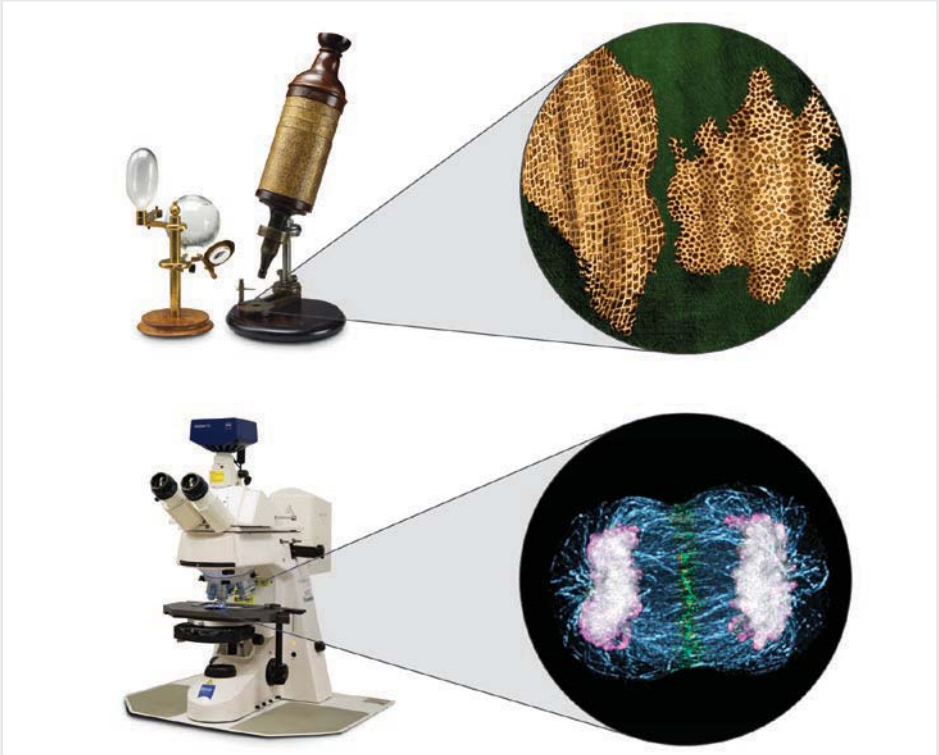
Analyze A sensory neuron serving the toe of a giraffe has an average length of nearly 4.6 meters. Use what you have learned about cell surface area and volume to explain how this cell can function properly.

A Brief History of Cell Theory

In order to learn more about cells and how they function, scientists first depended on simple instruments. Over time, advancements in science and technology resulted in microscopes that allowed us to not only see cells, but to observe processes occurring within them.

Before the 1600s, people had no idea that cells existed, and so had other explanations for the basis of life. That all began to change after the English scientist Robert Hooke first viewed cork under a microscope. He observed that cork is made of tiny, hollow compartments. The compartments reminded Hooke of small rooms found in a monastery, so he gave them the same name: cells. However, it took nearly 200 years before scientists made the connection between biological cells and life.

FIGURE 8: The cells viewed under Hooke's microscope are from cork, dead plant tissue. The cell viewed under the modern microscope is in the process of dividing.



Predict Advances in which fields most likely influenced changes in microscope technology?

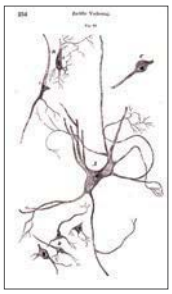
Cell Theory

Almost all cells are too small to see without a microscope. Magnifying lenses had already been around for hundreds of years before Robert Hooke developed his microscope, but their quality was limited by the lens-grinding technology of the times. Therefore, even though Robert Hooke had designed a state-of-the-art microscope for his time, he would most likely not have seen anything inside the cork cells when he studied them, even if they had been alive. So how did scientists come to learn so much about cells, and how long did it take?

FIGURE 9: A timeline of the study of cells

1595 Zacharias Janssen
Dutch eyeglass maker who invented the compound microscope by placing two lenses in a tube.

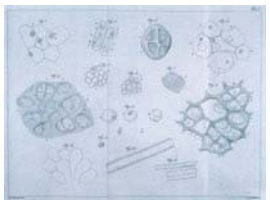
1674 Antonie van Leeuwenhoek
Dutch tradesman who developed a more powerful microscope. He observed numerous single-celled organisms swimming in a drop of pond water, which he called "animalcules."



1855 Rudolf Virchow
German scientist who stated that all cells come from other cells. He also described the microscopic structure of cells such as nerve cells.

1665 Robert Hooke
English scientist who used a three-lens compound microscope to examine thin slices of cork from an oak tree (Figure 8). He called the tiny, hollow compartments he saw "cells."

1838 Matthias Schleiden
German botanist who used compound microscopes to study plant tissue and proposed that plants are made of cells.



1839 Theodor Schwann
German animal physiologist who noticed structural similarities between plant cells and the animal cells he had been studying. He concluded that all living things are made of cells and cell products.

Analyze Using the development of cell theory as an example, make a claim for how science influences technology and technology influences science.

The cell theory is one of the first unifying concepts developed in biology. Theodor Schwann, influenced by the work of Matthias Schleiden and other scientists, published the first statement of the cell theory. Schwann's theory helped lay the groundwork for all biological research that followed. However, Schwann stated in his publication that cells form spontaneously by free-cell formation. As later scientists studied the process of cell division, they realized that this part of Schwann's idea was wrong. The cell theory is an example of a theory that changed over time as new discoveries were made.

The major principles of the cell theory are:

- All organisms are made of cells.
- All existing cells are produced by other living cells.
- The cell is the most basic unit of life.

Explain Before the cell theory was developed, many people claimed that spontaneous generation was possible. In other words, that cells arose from nonliving matter, such as dust or rotting meat. Respond to that claim using the principles of cell theory.

Hands-On Lab

Modeling Cell Surface Area-to-Volume Ratio

Cells must transport materials across their membranes in order to maintain homeostasis. In this lab, you will use model cells to investigate the relationship between cell size and homeostasis. Your model cells will consist of agar cubes of different sizes. Agar is a gel-like material used as a growth medium for bacteria. The agar has been soaked in an indicator that turns pink when exposed to a basic solution. The indicator will allow you to measure how quickly materials diffuse across the model cell's membrane.

SAFETY

Sodium hydroxide is corrosive. Wear goggles and gloves, and dispose of chemicals as instructed by your teacher.

PROBLEM

How does a cell's size affect its ability to maintain homeostasis?

PREDICT

Make a prediction for how the diffusion of materials into the cell will change as the model cell gets larger. Explain your reasoning.

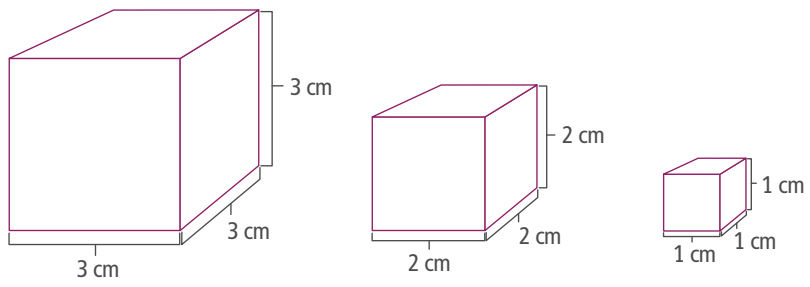
MATERIALS

- beaker, 250 mL
- graduated cylinder, 100 mL
- knife, plastic
- metric ruler
- paper towel
- phenolphthalein agar
- sodium hydroxide solution (1.0 M HCl), 100 mL
- spoon, plastic
- timer

PROCEDURE

1. Make three model cells by using the knife to cut three cubes from the phenolphthalein agar. Cell A should be 3 cm on each side, cell B should be 2 cm on each side, and cell C should be 1 cm on each side. Use the ruler to make exact measurements.

FIGURE 10: The cube-shaped cells model what happens to the volume as surface area increases.



Cell A Cell B Cell C

2. Calculate the total surface area of each cell. Record your data in a data table.

$$\text{surface area of a cube} = \text{length} \times \text{width} \times \text{number of sides}$$

3. Calculate the volume of each cell. Record your data.

$$\text{volume of a cube} = \text{length} \times \text{width} \times \text{height}$$

4. Calculate the surface area-to-volume ratio for each cell. For example, if the surface area was 27 cm^2 and the volume was 9 cm^3, the surface area-to-volume ratio would be 3:1. Record your data.
5. Put the model cells in the beaker. Carefully cover them with sodium hydroxide solution, which turns the agar pink.
6. Soak the cells in solution for four minutes. Use the spoon to turn the cells repeatedly throughout that time.
7. Remove the cells from solution and gently dry them on the paper towel.
8. Use the knife to cut each cube in half. Measure the distance (in cm) from the edge of the cell to the inner edge of the pink line. This shows how far the sodium hydroxide diffused. Record your data.

ANALYZE

1. How does the surface area-to-volume ratio change as cell size increases?
2. Identify which cell turned pink in the greatest proportion, and explain how this relates to cell size and diffusion.

EXPLAIN

Write an explanation that addresses each of the points below.

Claim How is a cell's size related to its ability to maintain homeostasis by transporting materials across the membrane? Was your prediction correct?

Evidence What evidence from your data supports your claim?

Reasoning Explain how the evidence you cited supports your claim.

REFINE

Explain whether the model used in this investigation provided an adequate level of accuracy and how you would change the model for future investigations.

Precision and accuracy Did the model provide the level of precision needed to make a valid conclusion?

Propose changes What changes would you make to this model if you were to carry out this investigation again? Why would you make these changes?

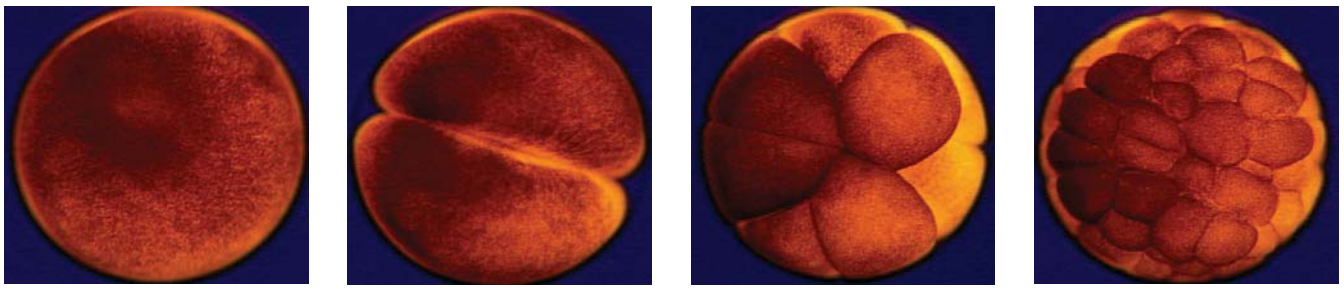
MEASURING CELL DIVISION | CELL BIOLOGIST: CANCER RESEARCH | Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 11: All plants and animals begin with a single cell. One cell divides into two, each of which will then divide. This pattern continues until an organism is formed.

Explore Online



Cells have a life cycle made up of periods of rest, growth, and division. When a multicellular organism develops, a single cell divides over and over to produce the trillions of cells that make up the organism. Throughout the organism's lifetime, internal and external signals regulate cell growth and cell division. These factors include physical and chemical signals, as well as limits on cell size.

Explain Refer to the notes in your evidence notebook to construct an explanation for why cells divide instead of simply growing larger. In your explanation, address the following questions.

1. How are the cell cycle and cell division related to the growth, development, and maintenance of the organism?
2. How do different factors influence cell growth and cell division?
3. How has technology influenced our understanding of cells and cell division?

CHECKPOINTS

Check Your Understanding

1. Which of these is *not* a principle of the cell theory?

a. The cell is the basic unit of life.

b. All living things are made of cells.

c. All organisms are made up of many cells.

d. All cells come from other cells.

2. Which term describes the resting phase of the cell cycle?

a. mitosis

b. interphase

c. prophase

d. telophase

3. Which of these best explains how advancements in technology influenced the development of the cell theory?

a. Communication between scientists improved.

b. Microscopes enabled scientists to see cells.

c. Increased knowledge allowed scientists to make predictions.

d. Printing increased the number of books about the cell.

4. In which of these situations would cells most likely receive signals instructing them to enter the M phase of the cell cycle? Select all correct answers.

a. A tissue needs repairing.

b. Cells need to grow larger.

c. More cells are needed to defend the body.

d. Cells need to decrease in number during development.

5. Place these events in the correct order to illustrate the sequence of events in the cell cycle.

a. Mitosis occurs, and one cell divides into two.

b. DNA is replicated to make two copies.

c. Organelles are copied, and the cell grows.

d. Additional growth occurs before the cell divides.

6. Imagine a cell has six sides, each measuring 4 micrometers (μm) in length. Use this information to answer the following questions.

a. What is the surface area of the cell?

b. What is the volume of the cell?

c. What is the surface-area-to-volume ratio for the cell?

d. If this cell grew larger in size, how would the transport of materials across the cell membrane be affected? How does this relate to the cell's ability to maintain homeostasis?

7. Complete this statement using these terms:

growth factors, *cyclins*, *volume*, *surface area*

Different factors regulate cell growth and division. Cells are limited in size because they need a large _____ as compared to their _____. This ensures that materials can move into and out of the cell at adequate rates. The cell cycle is also regulated by external factors such as _____ and internal factors such as _____. These factors work together to make sure the cell enters the appropriate phase of the cell cycle at the correct time.

8. Use an example to explain how apoptosis contributes to the growth and maintenance of an organism.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main idea from this lesson:

The cell cycle is a sequence of events in which cells grow and divide. Internal and external factors regulate the cell cycle to ensure that cells grow and divide at appropriate times.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

Consider how models help scientists learn more about cells, the cell cycle, and how cells maintain homeostasis.

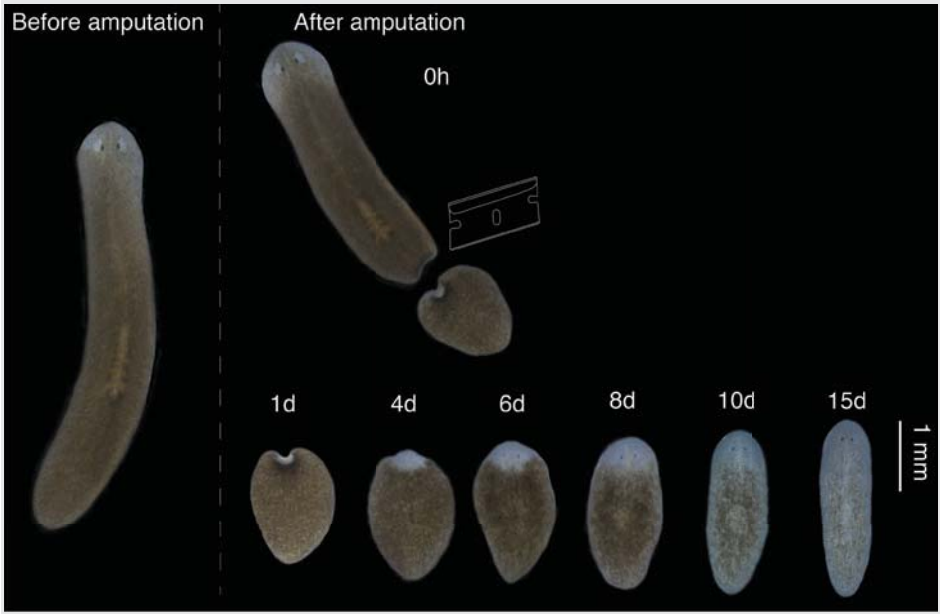
5.2

Mitosis and Differentiation

HeLa cells, a line of cancer cells used for research, can divide indefinitely.

CAN YOU EXPLAIN IT?

FIGURE 1: When planarians are cut into multiple pieces, each piece regenerates to form a complete organism.



Gather Evidence Record observations describing what happens to the part of the planarian that was amputated. How does this piece change over time?

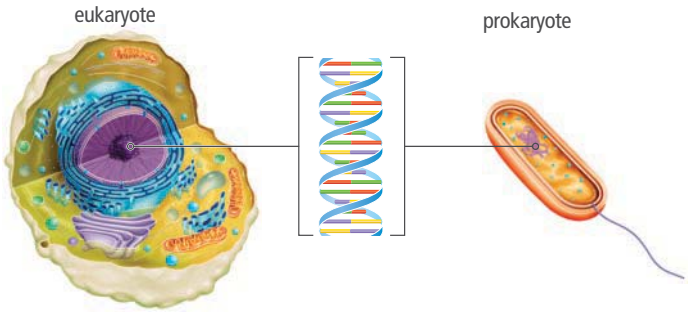
Planarians are free-living flatworms usually found in freshwater. They prefer the dark and are often found on the undersides of rocks in streams and ponds. Within their bodies are simple organ systems, including a digestive system, a reproductive system, and a simple nervous system. The nervous system is made up of a small brain and two long nerve cords that run along the body. Planarians are interesting to scientists because they can regenerate. If a planarian is cut in half, both halves regenerate to form a complete planarian. Each resulting organism will have a head, two eyespots, and a full set of internal organs.

Predict How do you think organisms like the planarian regenerate parts of their body? How could humans benefit from this knowledge?

Chromosomes

An important part of cell division is the replication and division of the cell's genetic material. In all organisms, DNA is the genetic material that contains information that determines an organism's inherited characteristics. This information provides instructions for not only the growth and development of each cell, but also for the organism as a whole.

FIGURE 2: DNA is the genetic material found in both prokaryotic and eukaryotic cells.



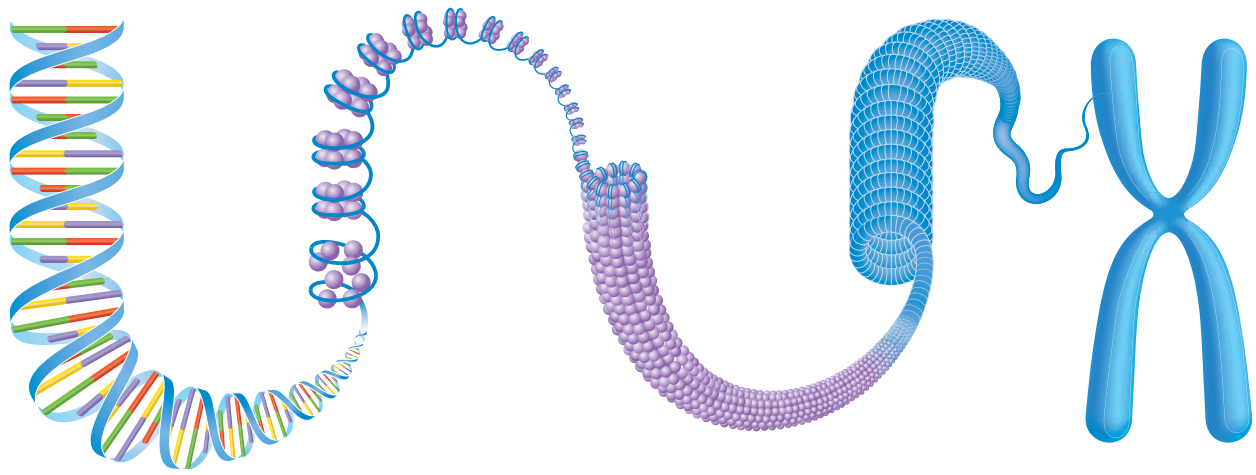
Analyze What does this model tell you about the structure and location of DNA in prokaryotic and eukaryotic cells?

DNA and Chromosomes

A chromosome is one long continuous thread of DNA that consists of many genes. Your body cells have 46 chromosomes each. If stretched out straight and laid end to end, the DNA in just one of your cells would be about 3 meters (10 feet) long! How does it fit inside the nucleus of a microscopic cell?

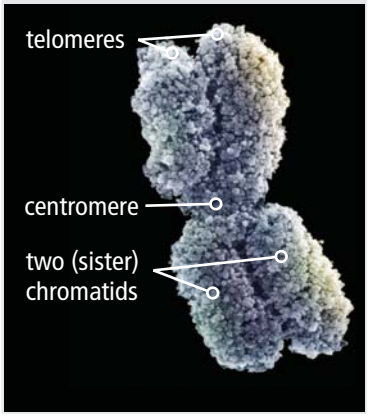
Collaborate Describe to a partner what happens to the chromosome as the cell progresses into mitosis.

FIGURE 3: Chromosome structure changes as the cell prepares for cell division.



Each double-stranded DNA molecule makes one chromosome.	DNA wraps at regular intervals around proteins called histones, forming chromatin.	Interactions between parts of the histones further compact the DNA.	The DNA coils more and more tightly around organizing proteins, forming supercoiled DNA.	The condensed, duplicated chromosomes can be aligned and separated during mitosis.
Interphase			Mitosis	

FIGURE 4: A duplicated chromosome is made up of two sister chromatids held together at the centromere.



During interphase, the combination of DNA and proteins is loose—you can think of it like a plate of spaghetti. During this phase, proteins must access specific genes for a cell to make specific proteins or to copy the entire DNA sequence. However, changes start to occur in the structure of the DNA as a cell prepares to enter mitosis.

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

Model Create a model to illustrate the meanings of these terms: DNA molecule, chromosome, chromatin, chromatid, and centromere.

Engineering

FIGURE 5: Lobsters are referred to as "immortal" because they do not appear to die from old age.

Can We Turn Back the Clock on Aging?

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

The loss of telomeres over time has been linked to aging in organisms. However, some organisms, such as lobsters, are able to regenerate their telomeres with the help of an enzyme called telomerase. Therefore, lobsters are able to remain "young" their entire lives, growing and maintaining a strong metabolism until they die. Scientists are currently studying ways to control telomere length in humans. These applications could be used to delay the aging process by preventing cell death from telomere loss, or they could be applied to diseases such as cancer by preventing the rebuilding of telomeres in cancer cells.

Analyze Scientists are currently studying ways telomerase could be used to slow down aging and fight diseases like cancer. How might these studies influence society?

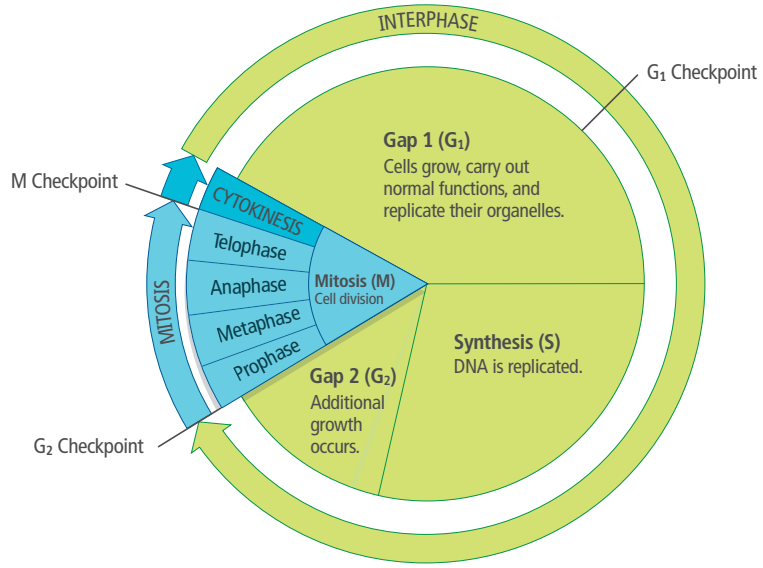
Explain Answer the following questions about DNA and cell division.

1. DNA must be coiled into special structures before a cell divides. Why do you think it is necessary for the DNA to be structured this way before cell division occurs?
2. Every cell in your body originated from one cell. What does this mean about the DNA in each of your body cells?

Mitosis and Cytokinesis

Cells spend most of their time in the interphase part of the cell cycle. Interphase plays an important role in preparing the cell to divide. It provides critical time for the duplication of organelles and DNA replication as well as cell growth. By the end of interphase, the cell's DNA and organelles have been replicated, and the cell is large enough to divide.

FIGURE 6: The cell cycle is an orderly process that prepares the cell for division.



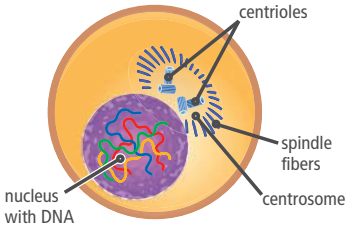
Explain Do you think this model of the cell cycle is accurate for all cells? Explain your answer.

After interphase, the cell undergoes the fourth stage of the cell cycle—mitosis. Mitosis is the stage during which cell division takes place. At the end of mitosis, the process of cytokinesis divides the cell cytoplasm. The result is two daughter cells that are genetically identical to the original, or parent, cell.

Collaborate Discuss this question with a partner: How do you think the cell divides its DNA evenly to give each daughter cell an identical copy of the genetic material?

Specialized structures called centrosomes are involved in mitosis in animal cells. The centrosome is a small region of cytoplasm that produces protein fibers called microtubules. Centrioles are cylinder-shaped organelles made of short microtubules. Before an animal cell divides, the centrosome, including the centrioles, doubles and the two new centrosomes move to opposite ends of the cell. Microtubules grow from each centrosome, forming spindle fibers. These fibers attach to the DNA and help it divide between the two cells.

FIGURE 7: Centrosomes contain structures called centrioles. Spindle fibers are organized at the centrosome.



The Cell Cycle in Detail

Explore Online

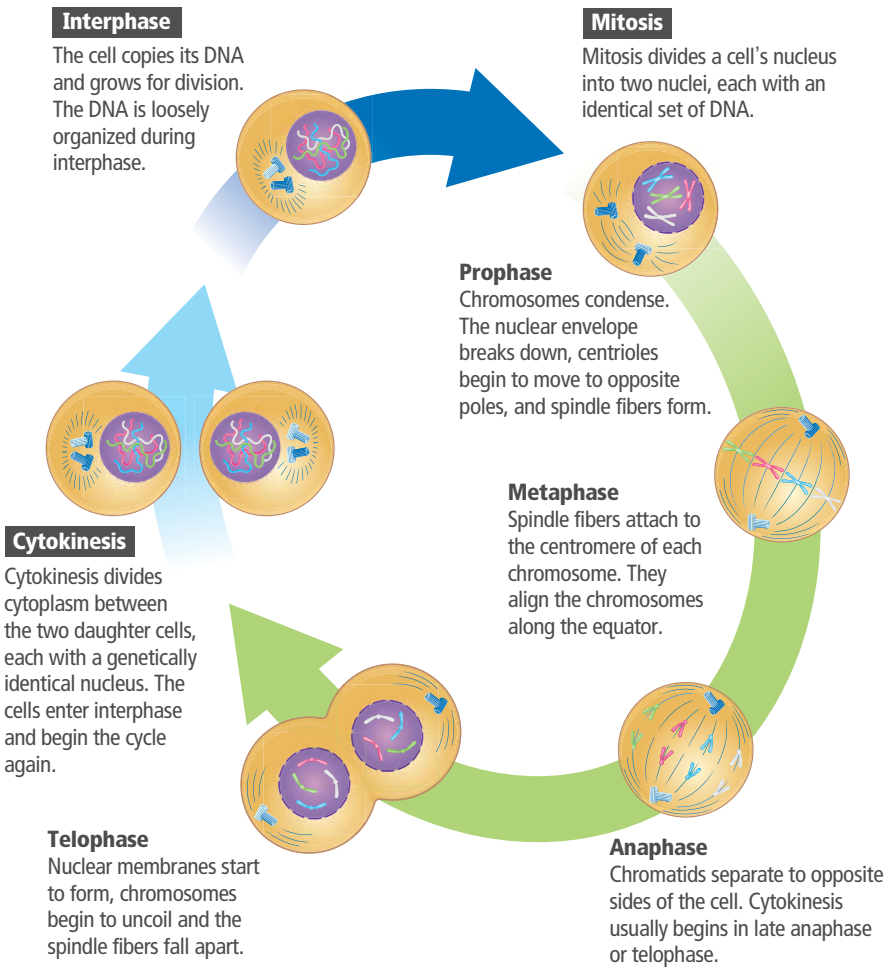
Hands-On Activity

Animating Mitosis Make a flipbook to model the stages of mitosis in action.

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

FIGURE 8: The Cell Cycle

Explore Online



Analyze What mechanisms ensure that each cell receives an identical set of DNA during mitosis? Use evidence from Figure 8 to support your answer.

Systems and System Models

Use the model of the cell cycle shown in Figure 8 to answer the following questions.

1. Human cells have 46 chromosomes. How many chromosomes should be present during the G_2 phase of the cell cycle? How many should be in each daughter cell after cytokinesis? Explain your answers.
2. How would you describe the phases of mitosis in your own words?

Asexual Reproduction

Reproduction is a process that makes new organisms from one or more parent organisms and can occur in one of two ways—sexually and asexually. Sexual reproduction involves the joining of two specialized cells called gametes (eggs and sperm cells), one from each of two parents. Sexual reproduction requires two parents and takes longer, but it produces offspring that are genetically unique because they have a mixture of genes from both parents.

Asexual reproduction can occur relatively quickly, and the offspring are genetically identical to the parent organism. Prokaryotes and some eukaryotes reproduce asexually. Remember that prokaryotes do not have a nucleus. This typically allows prokaryotic cells to divide much faster. Because prokaryotes are single-celled, the resulting daughter cells are new single-celled organisms. The offspring that result are, for the most part, genetically identical to each other and to the original single-celled parent.

Predict Although bacteria and other single-celled organisms can produce genetically identical offspring, they sometimes still exchange DNA by passing it from bacterium to bacterium. What might be the advantage of exchanging DNA in this way?

Binary Fission and Mitosis

Prokaryotes, such as bacteria, lack not only a nucleus but also membrane-bound organelles and spindle fibers. Prokaryotes also have much less DNA than most eukaryotes have. The DNA of most bacteria is in the form of a single circular chromosome, instead of the linear chromosomes found in your cells.

Bacteria reproduce through a process called binary fission, which differs from mitosis in several ways. Binary fission starts when the bacterial chromosome is copied. Both chromosomes are attached to the cell membrane on opposite sides of the cell. As the cell grows and gets longer, the chromosomes move away from each other. When the cell is about twice its original size, it undergoes cytokinesis. The membrane pinches inward, and a new cell wall forms between the two chromosomes, which completes the separation into two daughter cells.

FIGURE 10: Models of binary fission and mitosis

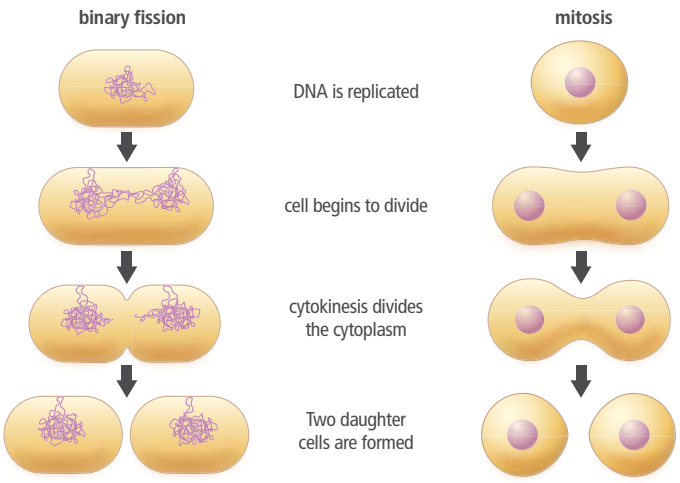
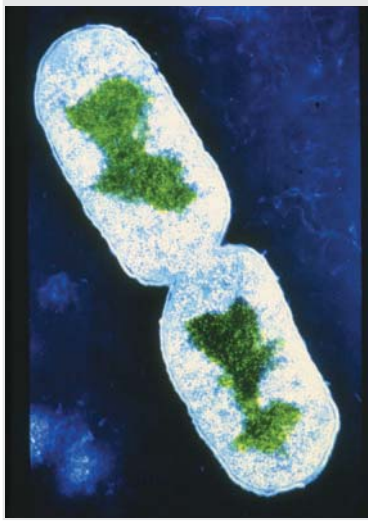


FIGURE 9: In binary fission, the original cell divides into two genetically identical cells.

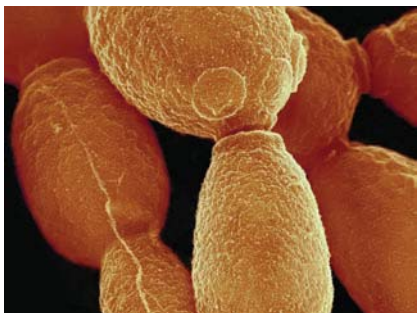


Model Construct a Venn diagram comparing binary fission and mitosis.

Mitotic Reproduction

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

FIGURE 11: Forms of mitotic reproduction



Budding A new genetically identical individual cell forms on the body of the parent cell.

Vegetative Reproduction Multicelled structures from an organism develop into a new genetically identical organism.

Fragmentation A piece of an organism grows into a new genetically identical organism.

Both sexual and asexual reproduction are utilized in farming, industry, and scientific research. Food crops such as strawberries and almonds are pollinated by bees. These and other pollinators help plants carry out sexual reproduction and produce fruit. Horticulturists and home gardeners can use fragmentation and vegetative reproduction to produce new plants. For example, a piece of a leaf from an African violet plant can grow into a new African violet plant. Potato plants can be grown by planting a piece of potato that contains an "eye" in the garden.

Binary fission and budding are also widely used in industry. Many drugs, such as vaccines and insulin, are produced by growing colonies of bacteria that have been genetically modified to produce the drug. Millions of people with diabetes use synthetic insulin, which is produced by genetically modified bacteria or yeast.

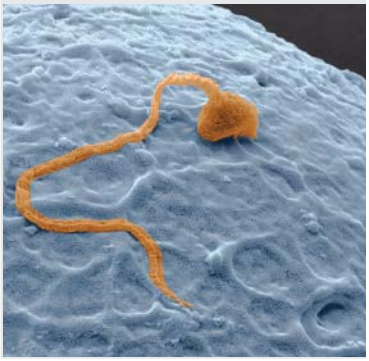
Collaborate If you wanted to grow a food crop for human consumption, which do you think would be best for the plant to use—sexual or asexual reproduction? Write your argument and explain it to a partner.

Model Develop a model to illustrate how mitosis results in two genetically identical daughter cells. Include chromosomes in your model, and use different colors, materials, or symbols to show how the cell duplicates, organizes, and separates chromosomes during interphase and mitosis.

Cell Differentiation

A skin cell can divide to make a new skin cell, or a single bacterium can generate another bacterium. But how does a complex organism like you develop? Your body began as a single fertilized egg, or zygote. If the egg simply divided to make lots of identical cells, it would not form a baby.

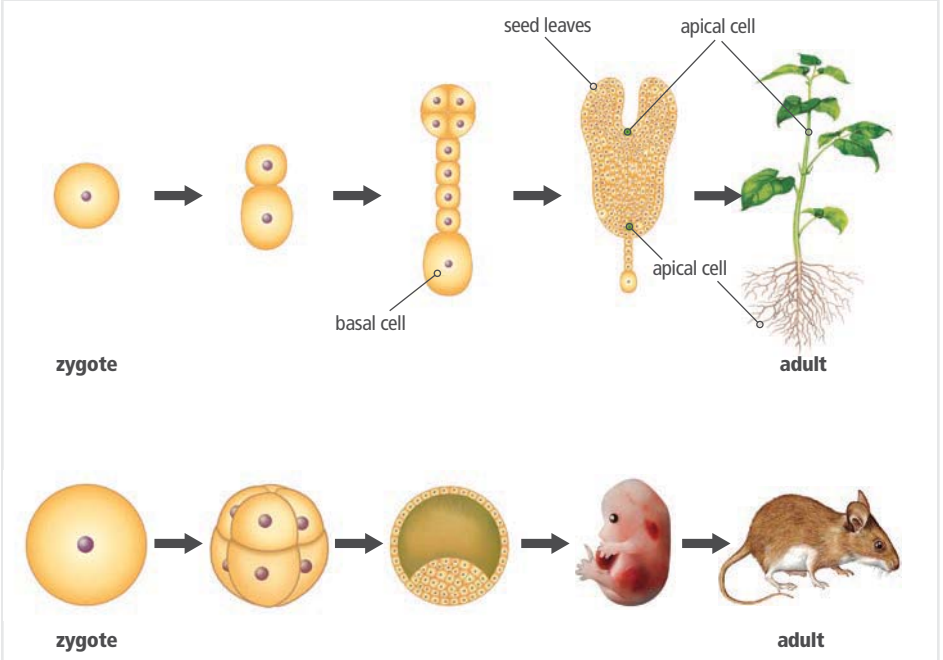
FIGURE 12: A sperm and egg fuse during fertilization, and a zygote is formed.



Development of Multicellular Organisms

Embryonic development begins with the fertilization of an egg by a sperm, producing a zygote. The zygote undergoes a series of divisions to produce a mass of cells that then become specialized. Cell differentiation is the process by which a cell becomes specialized for a specific structure and function during the development of a multicellular organism.

FIGURE 13: Cell differentiation in a plant and an animal



A cell's location within an embryo helps determine how it will differentiate. In plant cells, the first division of a fertilized egg is unequal, or asymmetric, as shown above. The apical, or topmost, cell forms most of the embryo, including the growth point for stems and leaves. The basal cell provides nutrients to the embryo and serves as the growth point for the roots. Plant cells cannot easily migrate because of their cell walls, but they adapt to changing conditions and continue to develop throughout their lifetime. As the plant grows, new cells continue to differentiate based on their location in the plant.

Analyze Compare the model of cell differentiation in plants to the model of cell differentiation in animals. What are the differences, and what are the similarities?

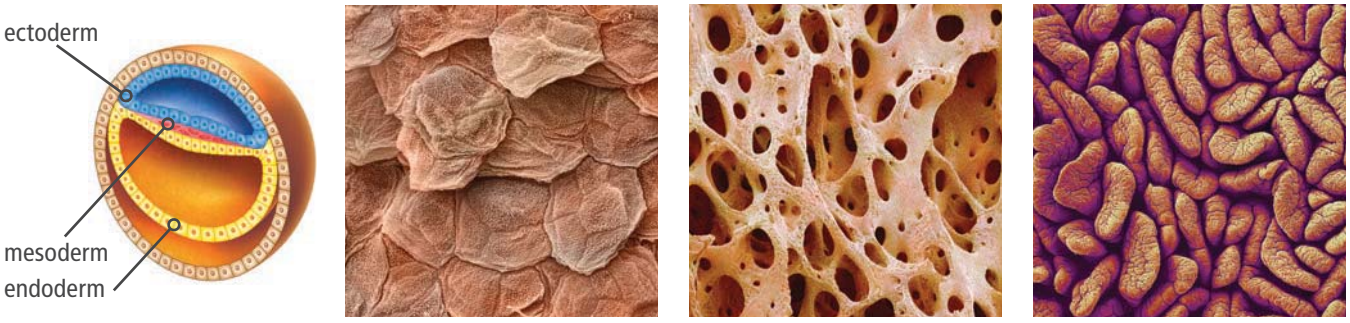
Explore Online

Hands-On Lab

Modeling Induction in Embryos Design a model to show how inducing chemicals trigger cell differentiation in a developing embryo.

In animals, an egg undergoes many divisions after it is fertilized. The resulting cells migrate to a specific area and begin to differentiate, forming a hollow ball. As the embryo develops, part of the ball folds inward, forming an inner layer called the endoderm. An opening is formed in the outer layer, called the ectoderm. Some animals, such as jellyfish, develop from only two cell layers. Vertebrates, including humans, develop a third layer of cells, called the mesoderm, between the inner and outer layers. This standard model of development varies from species to species.

FIGURE 14: Each cell layer in the gastrula of a human embryo produces cells that will form different tissues and organs.



a The gastrula is the embryo stage that develops three layers of cells: the ectoderm, mesoderm, and endoderm.

b The ectoderm develops into the skin and the nervous system. It also forms the lining of organs such as the mouth.

c The mesoderm develops into bone, muscle, blood, and connective tissue. It also forms organs such as the kidneys.

d The endoderm forms the lining of organs in the digestive, respiratory, and excretory systems. It also forms some glands.

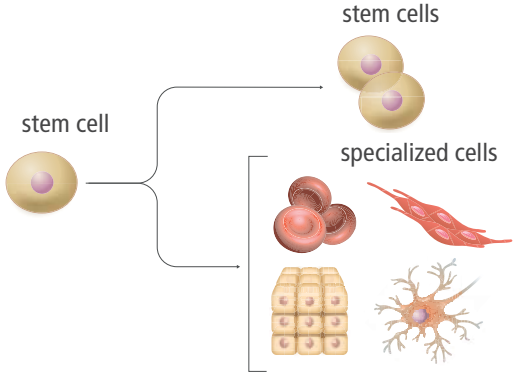
Explain Like the cell cycle, the process of cell differentiation is highly regulated. Write an argument for why regulation of the cell differentiation process would be especially important during the early stages of development.

Stem Cells

Specialized cells develop from a type of cell known as a stem cell. Stem cells are a unique type of body cell that can develop into a variety of specialized cells through differentiation. Stem cells are able to divide and renew themselves by mitosis for long periods of time, remaining undifferentiated until they are needed. When needed, they divide to form one new stem cell and one specialized cell.

Predict Describe a scenario in the human body in which a stem cell would need to divide into a new stem cell and a specialized cell.

FIGURE 15: Stem cells can develop into any type of cell.



Stem cells are classified by their potential to develop into differentiated cell types of different tissues. In general, the more differentiated a stem cell already is, the fewer the types of cells it can form. Stem cells are also classified by their origin, as either adult or embryonic. Adult stem cells are partially undifferentiated cells located near the specialized cells of many organs and tissues. Their primary role is to maintain and repair the specialized cells in tissues and organs, and the variety of specialized cell types they can produce are limited. Adult stem cells are found in small numbers all over the body in adults and children, as well as in umbilical cord blood.

Embryonic stem cells can form any of the 200 cell types of the body. They may be obtained from donated three-to-five-day-old embryos that result from in vitro fertilization. In vitro fertilization is a process in which eggs are fertilized outside a woman's body and go through several divisions in a culture. Scientists have also developed methods for converting differentiated cells, such as human skin cells, to embryonic stem cells.

Analyze Scientists are now able to convert human skin cells to embryonic stem cells. How might this technology influence science and society?

Researchers are studying ways to use stem cells to treat many different medical conditions. Because stems cells can differentiate into other types of cells, they offer the potential to repair or replace damaged tissues or organs. For example, stem cells in bone marrow produce red and white blood cells. Bone marrow transplants have been used for many years to treat leukemia and lymphoma, cancers that affect white blood cells. Scientists are also studying the use of stem cells to repair the pancreas of people with type I diabetes so that they will produce normal amounts of insulin. A patient with a damaged heart could potentially have stem cells injected into the tissue to repair the damage and grow new capillaries, thus restoring normal heart function. However, there are many technical problems with these treatments that future research needs to solve.

Collaborate Write a list of the tradeoffs you might consider when deciding whether to use stem cell treatments or traditional treatments to treat a disease like diabetes. Compare your list to a partner's list and mark the common items.

Gene Expression and Cell Differentiation

Virtually every cell in your body contains the same set of DNA, but every cell is not the same. How is this possible? A gene is a segment of DNA that stores genetic information. While almost every cell in your body has a full set of genes, each type of cell expresses only the specific genes it needs to carry out its function.

When a gene is expressed, or "switched on," the instructions within that segment of DNA are used to make proteins that carry out specific functions within the cell. When a gene is "switched off," or not expressed, its instructions are not used to make proteins. During development, genes are expressed differently in different types of cells. The set of genes expressed is determined by the type of cell and its location in the embryo or organism. By expressing some genes and not others, each cell generates the proteins it needs to take on its specific structure and function within the organism.

Model Make a model to illustrate how an organism develops from a zygote to a fully grown adult. In your model, include media and text to explain fertilization, cell division, and cell differentiation.

Guided Research

Studying Limb Regeneration

In the beginning of this lesson, a planarian was shown cut in half and then regenerating its body. Regeneration is the regrowth of a lost body part. This is common in some complex organisms, but as organisms become more complex, the ability to regenerate body parts becomes more rare. For example, humans do not have the ability to regenerate lost body parts. However, scientists think that by studying species that can regenerate and applying this knowledge to humans, we may someday be able to regrow lost limbs.

One species currently being studied is the Mexican axolotl, a type of salamander. This species is unusual in its ability to regenerate multiple structures such as limbs, skin, jaws, and even its spinal cord. In addition, the axolotl is incredibly resistant to developing cancer and it remains in its juvenile form for its entire life. As a result, this species is the focus of several scientific studies on limb regeneration and possible treatments for human diseases.

Perform your own research to find out how scientists are approaching this problem. Use the following questions to guide your research.

- What types of questions are scientists asking about limb regeneration?
- How are these questions being investigated?
- What types of advances are scientists hoping to make?
- What have scientists been able to achieve so far?
- What controversies has this type of research caused?
- How might this research be used to benefit humans?

As you conduct your research, evaluate your sources carefully to be sure they are reliable. Do they present verifiable facts? Are the opinions those of an expert or experts in this field? Is there enough evidence to show that reported successes are viable?

FIGURE 16: Salamanders such as this axolotl (*Ambystoma mexicanum*) can regenerate lost limbs.

Language Arts Connection

Make a webpage or blog to explain the latest advancements in limb regeneration. You may choose to focus on a specific species or line of research. Use audio, visual, and interactive elements to add interest and make the concepts you are explaining easy to understand. Include a list of sources in the format specified by your instructor.

A multimedia presentation combines text, sounds, and images. A successful multimedia presentation includes the following:

- clear and consistent focus
- ideas that are presented clearly and logically
- graphics, text, music, video, and sounds that support key points
- organization that is appropriate to its purpose and audience

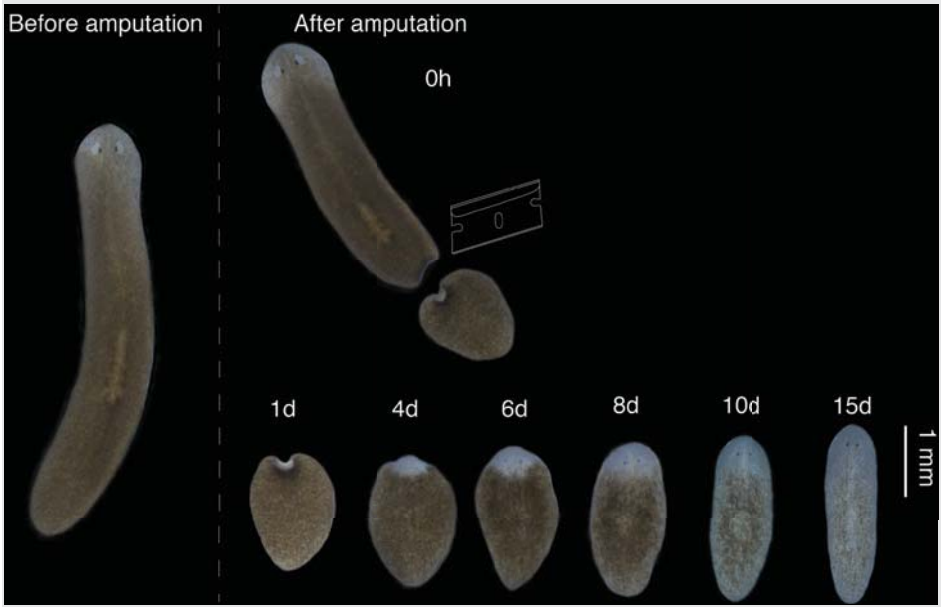
CYTOKINESIS IN PLANT AND ANIMAL CELLS | MITOSIS UNDER THE MICROSCOPE | MODELING INDUCTION IN EMBRYOS

Go online to choose one of these other paths.

Lesson Self-Check

CAN YOU EXPLAIN IT?

FIGURE 17: A planarian can regenerate removed body parts or their entire body.



Scientists study organisms that can regenerate parts of their body or their entire body, such as planarians, newts, and salamanders. Scientists have discovered that planarians have stem cells throughout their body. One of the reasons planarians are of such interest to scientists is that, even though they are a very simple organism, they have a centralized nervous system that they can restore to full function during the regeneration process. They can even regrow brain tissue from stem cells! The size of the planarian fragment does not matter. Even a piece that is 1/279 of the original animal can be restored to a full-sized planarian, which would be similar to growing another human from someone's cut-off nose.

Explain Construct an explanation for how cell division and differentiation help organisms such as planarians to regenerate parts of their body. Your response should answer the following questions.

1. What is the role of mitosis in regenerating tissues?
2. How are stem cells involved in the process of regeneration?
3. What is the role of cell differentiation in the development of the organism?
4. How could knowledge of this process be used to help humans?

CHECKPOINTS

Check Your Understanding

1. Which of these statements can be used to describe a chromosome? Select all correct answers.

- **a.** A chromosome is a long, continuous strand of DNA.
- **b.** Histones are proteins that are only present during mitosis.
- **c.** Chromosomes are tightly packed during mitosis.
- **d.** Chromosomes float freely around the cell of eukaryotes.
- **e.** Telomeres are chromosome regions that lack genes.
- **f.** Each chromosome contains only one gene.

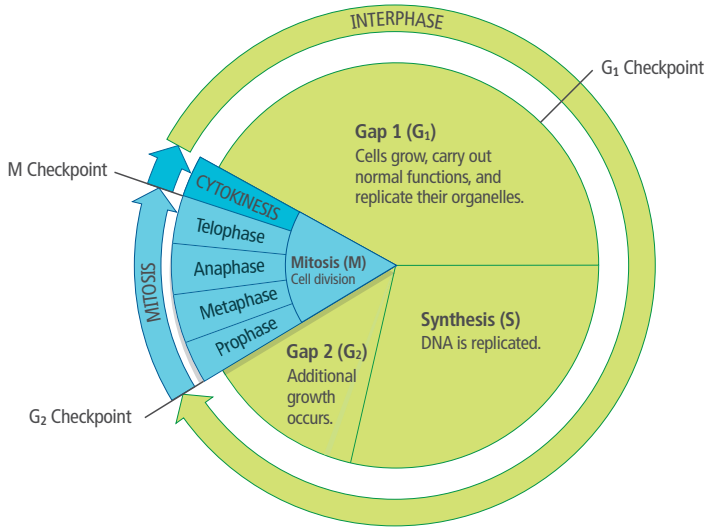
2. Place these steps in order to describe the changes that occur in the organization of the chromosome as the cell progresses into mitosis.

- **a.** The chromosome coils more and more tightly, forming supercoiled DNA.
- **b.** Condensed, replicated chromosomes attach at a pinched region called the centromere.
- **c.** DNA is wrapped around histones at regular intervals, forming chromatin.
- **d.** Interactions between parts of histones compact the DNA.

3. In which of these scenarios would the rate of mitosis most likely increase? Select all correct answers.

- **a.** A tissue is damaged and requires repair.
- **b.** A tissue needs to decrease in size during embryonic development.
- **c.** A person has a "growth spurt" and grows taller.
- **d.** A tissue loses a large number of cells due to wear and tear.

FIGURE 18: Phases of the Cell Cycle



4. Identify the phase of mitosis described in each step, and then put the steps in the correct order.

- **a.** Cell membrane pinches inward, dividing the cytoplasm and its contents.
- **b.** Nuclear membrane reforms and chromosomes uncoil.
- **c.** DNA and histones condense; nucleus begins to break down.
- **d.** Chromatids separate and move to opposite sides of the cell.
- **e.** Chromosomes line up along cell equator; spindle fibers attach to each chromosome.

5. Which events take place during mitosis but not during binary fission? Select all correct answers.

- **a.** duplication of organelles
- **b.** division of the cytoplasm
- **c.** separation of chromosomes
- **d.** formation of a mitotic spindle

6. Explain the relationship between embryonic cell layers, gene expression, proteins, and cell differentiation.

7. Use Figure 18 to construct an explanation for how the cell prepares for cell division. Which events take place before mitosis, and how do these prepare the cell to divide?

8. Use the following terms to complete the statement:

endoderm, ectoderm, mesoderm

As an embryo begins to organize, it first develops into a hollow ball with a flattened cluster of cells at one end. The outer layer is called the ____ and will become an organism's skin and nervous system. The cluster of cells forms a tube through the center of the ball that will become the inner lining of the digestive tract and other organs. This layer is known as the ____. As the tube forms, some cells from the cluster migrate into the cavity of the embryo to become the ____. This layer will become muscle and bone and organs such as the kidneys.

9. Draw a diagram showing how mitosis produces a multicellular organism. Explain how differentiation completes the organism's development.

10. What would happen if mitosis took place in a cell but cytokinesis did not?

11. Draw a model to illustrate how the steps of mitosis ensure that each daughter cell receives an identical set of chromosomes. In your model, include at least three sets of chromosomes and add color or shading to differentiate the different sets of chromosomes. Include text explaining how each step of mitosis contributes to the process of separating the duplicated chromosomes in an orderly manner.

12. Use these terms to complete this statement about stem cells and cell differentiation:

    genes, neuron, proteins, differentiate

    Stem cells are a unique type of body cell that can _____ into a variety of specialized cell types. A stem cell can either divide into two new stem cells or it can can divide to produce one stem cell and one specialized cell, such as a _____. New advancements in science have allowed researchers to convert human skin cells to embryonic stem cells. This requires altering segments of DNA called _____. When these segments of DNA are expressed, the cell produces _____, which carry out specific functions within the cell.

13. Refer to Figure 19 to explain why stem cells are of great interest to researchers studying therapies for human diseases.

MAKE YOUR OWN STUDY GUIDE

In your Evidence Notebook, design a study guide that supports the main ideas from this lesson:

Chromosomes are long strands of DNA that condense as the cell prepares for cell division.

Mitosis and cytokinesis result in two daughter cells with identical genetic material.

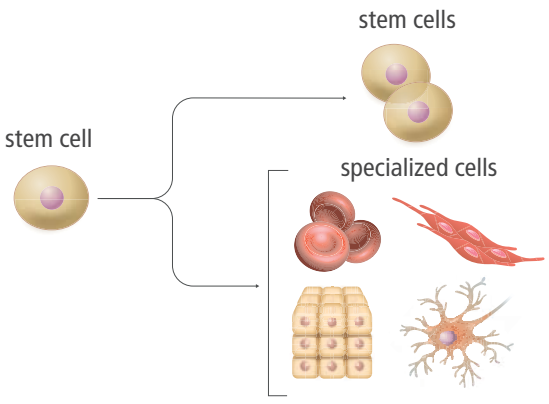
Cell differentiation is a process in which cells take on specialized roles within the organism. Different genes are expressed in different types of cells.

Remember to include the following information in your study guide:

- Use examples that model main ideas.
- Record explanations for the phenomena you investigated.
- Use evidence to support your explanations. Your support can include drawings, data, graphs, laboratory conclusions, and other evidence recorded throughout the lesson.

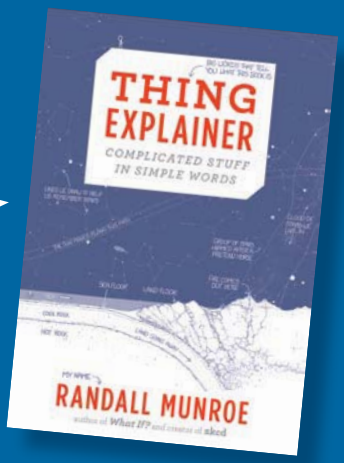
Consider how models of the cell cycle can be used to illustrate the process that allows one cell to divide into two genetically identical daughter cells.

FIGURE 19: Stem cells can differentiate into a variety of cell types.



THING EXPLAINER BY RANDALL MUNROE

A BOOK EXPLAINING COMPLEX IDEAS USING ONLY THE 1,000 MOST COMMON WORDS



RANDALL MUNROE
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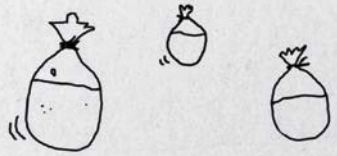
TINY BAGS OF WATER YOU'RE MADE OF

The very tiny parts of people and other animals

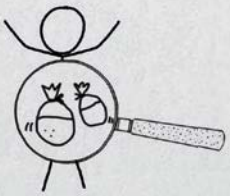
You've learned that a cell is the basic unit of life. Organisms are made of one or more cells, need energy for all of their functions, respond to their environment, and reproduce by passing their genetic information to offspring. Here's a description of animal cells in simple language.

THE STORY OF WHAT LIVING THINGS ARE MADE OF

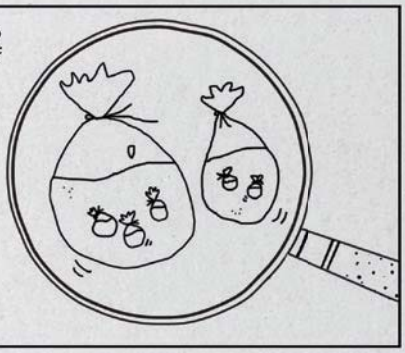
EVERYTHING THAT'S ALIVE IS MADE OF TINY BAGS OF WATER. SOME LIVING THINGS ARE MADE OF JUST ONE BAG OF WATER. THOSE THINGS ARE USUALLY TOO SMALL TO SEE.



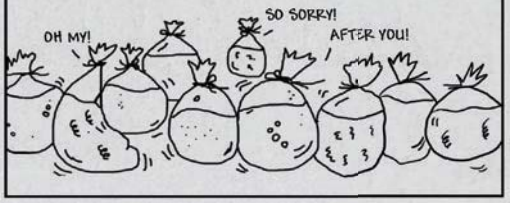
OTHER THINGS ARE MADE OF A GROUP OF BAGS STUCK TOGETHER. YOUR BODY IS A GROUP OF LOTS AND LOTS OF THESE BAGS THAT ARE WORKING TOGETHER TO READ THIS PAGE.



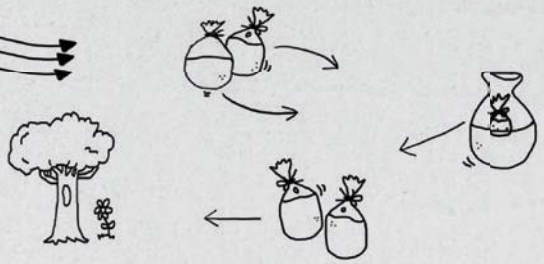
THESE BAGS ARE FULL OF SMALLER BAGS. LIFE USES LOTS OF BAGS.

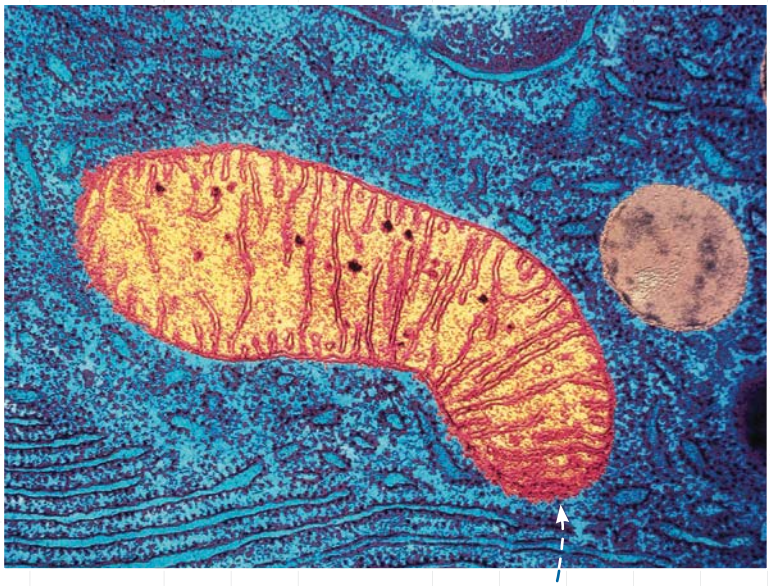


ALL LIFE IS MADE FROM DIFFERENT KINDS OF WATER, AND A BAG KEEPS THE STUFF INSIDE IT FROM TOUCHING THE STUFF ON THE OUTSIDE. BY USING BAGS, LIVING THINGS CAN KEEP DIFFERENT KINDS OF WATER IN ONE PLACE WITHOUT IT ALL COMING TOGETHER.



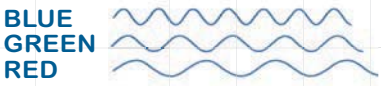
SOME OF THE LITTLE BAGS YOU SEE HERE WERE ONCE LIVING THINGS ON THEIR OWN. LONG AGO, SOME LITTLE GREEN BAGS LEARNED TO GET POWER FROM THE SUN. THEN THEY GOT STUCK INSIDE OTHER BAGS, AND THOSE BECAME FLOWERS AND TREES. THE GREEN COLOR OF LEAVES COMES FROM THE CHILDREN OF THOSE LITTLE GREEN BAGS.





SIZE

These bags are almost always too small to see. In fact, they're almost as small as the waves of light we see with:



LITTLE ANIMALS

These are living things (not really "animals") that got stuck in our bags of water a long time ago, like the green things in tree leaves. Now we can't live without each other. They get food and air from our bodies and turn them into power for our bags.

INFORMATION

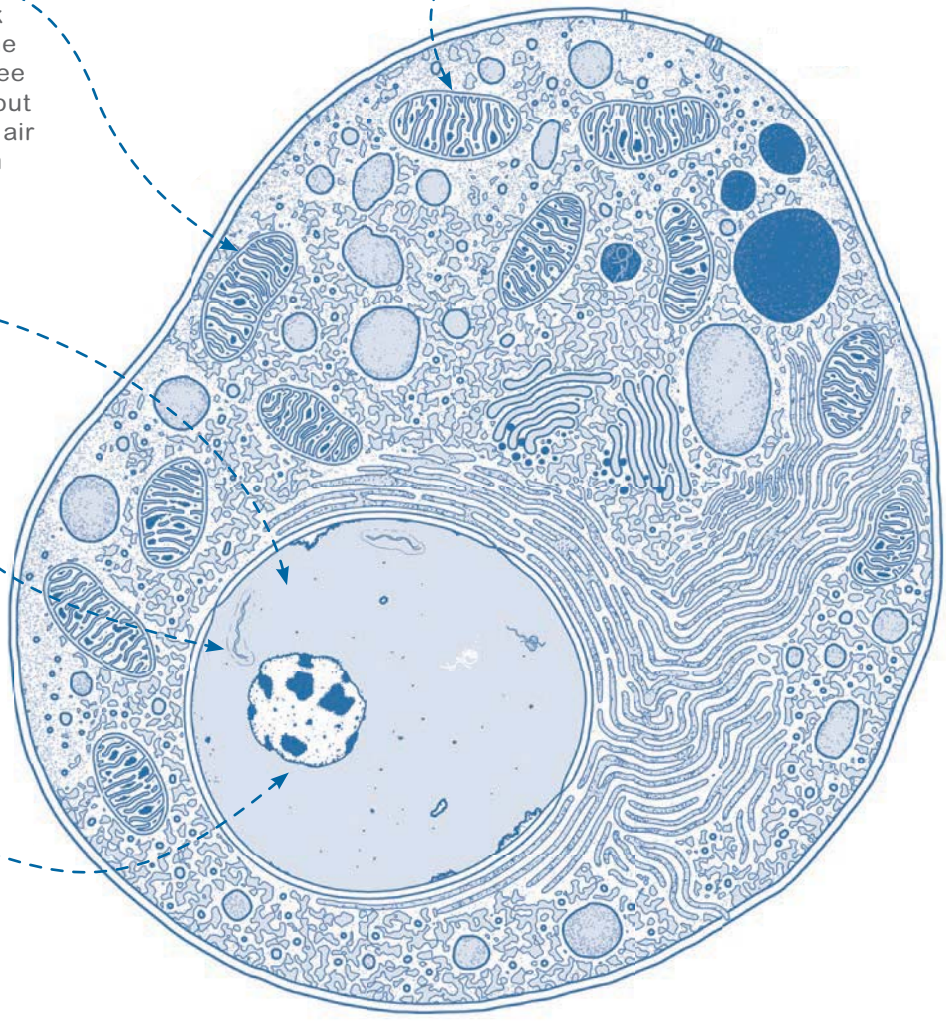
The information for how to make different body parts is stored here.

READERS

These machines read the information about how to make parts and write it on little notes, then send them out through the holes in the wall.

MACHINE MAKER

This part makes the little machines that sit outside the control area.



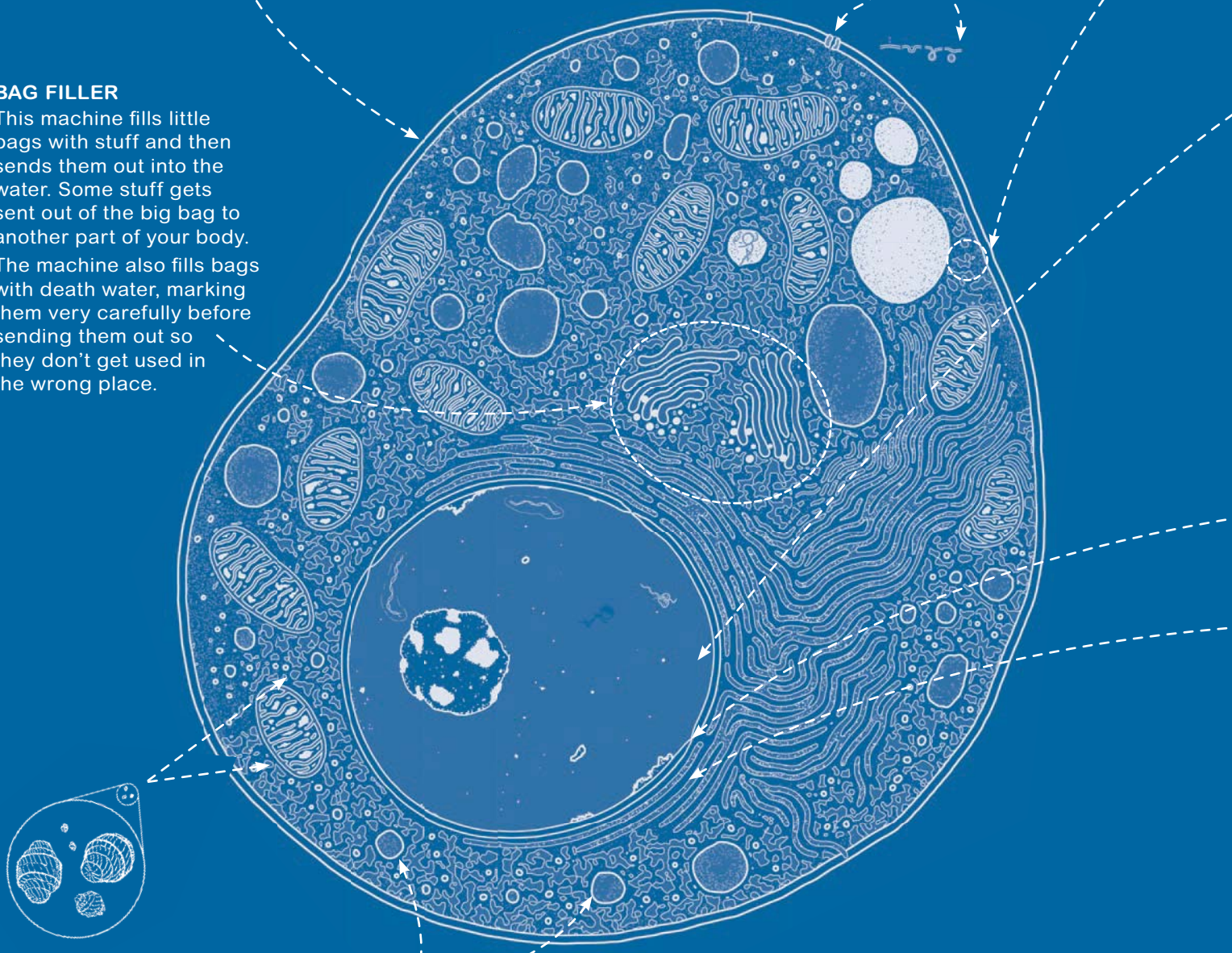
TINY BAGS OF WATER YOU'RE MADE OF

OUTSIDE WALL
The water bags that make up animals have soft walls. The bags in trees and flowers, which don't need to move around as much as us, have a less soft outside layer.

GETTING IN AND OUT
Some things can go through the bag's wall on their own. Other things can only go through if the bag helps them, either by letting them through an opening, or by making part of the wall into a new bag to hold them.

BAG FILLER
This machine fills little bags with stuff and then sends them out into the water. Some stuff gets sent out of the big bag to another part of your body.

The machine also fills bags with death water, marking them very carefully before sending them out so they don't get used in the wrong place.



STRANGE BOXES
There are lots of these little boxes in our water bags. We don't know what they do.

BAGS OF DEATH WATER
These little bags are full of a kind of water that breaks things into tiny pieces. If something is put inside them, the water breaks it down into whatever it's made of.

If something goes wrong, these little bags tear open and all their bad water falls out. That makes the whole bag around it fall to pieces and die.

"Bags falling to pieces" sounds bad, since bags are what you're made of. But if a bag was having problems, it could hurt you. The death water helps clear it away so your body can make a new one.

BAG SHAPERS
The space between bag parts is full of lots of very thin hair-like lines. These are like bones for the bag; they help hold its shape, and do some other things.

Some of these shapers also have holes down the middle, and can carry things from one part of the bag to another.

EMPTY POCKETS

This part of the bag has pockets to hold stuff that it might need later. It also makes a few things.

One of the things it makes is that stuff that helps your arms and legs get stronger. Sometimes, people who want to run or ride fast will put bottles of that stuff into their body and then lie about it.

CONTROL AREA

This area in the middle holds information about how to make the different parts of your body. It writes this information in notes and sends them out into the bag.

Bags make more bags by breaking in half. When this happens, the control area also breaks in half, and each half gets a full set of the bag's information.

Not all bags have these control areas. The bags in human blood don't (which means blood can't grow) but the bags in bird blood do.

This control area may have once been a living thing on its own, just like the green things in leaves.

CONTROL AREA HOLES

Notes and workers go out through these openings.

LITTLE BUILDERS

This area is covered in little building machines that build new parts for the bag. The builders sit just outside the control area, reading the notes from inside that tell them what to build.

After the builder makes a part, the part falls away into the bag. Each part has a job to do. Maybe its job is to tell another part it's time to stop working. Maybe its job is to turn one kind of part into another. Maybe it makes another part do something different. Or maybe it has a job, but waits until it sees *another* part before it starts working.

The strange thing is, no one tells the part where to go. It just falls out into the room with all the other parts, and hangs around until it runs into whatever part it's supposed to grab. (Or until another part grabs *it!*) This sounds strange, and it is! There are so many parts, and they're all grabbing each other and stopping each other and helping each other.

The insides of these bags are harder to understand than almost anything else in the world.

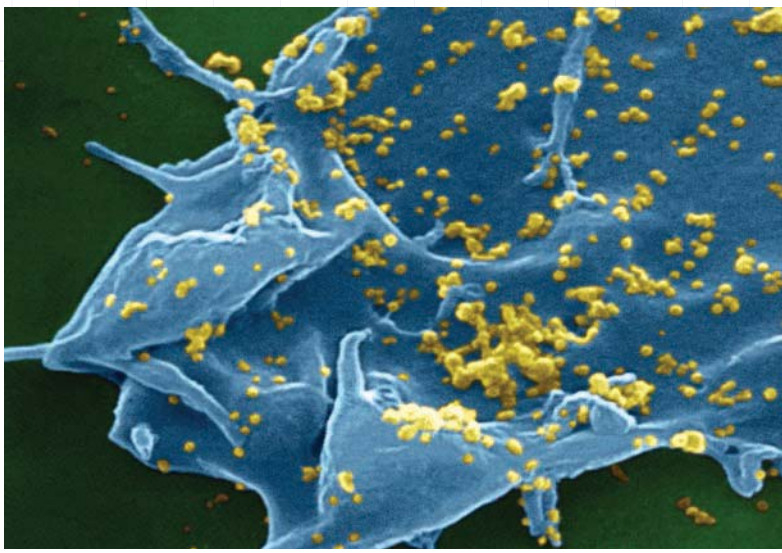
Go online for more about *Thing Explainer*.

THINGS THAT MAKE YOU SICK

These tiny things can get into your bags and take control of them. When they do that, they use the bag to build more of them.

When the kind shown here gets into you, your body gets hot, your legs hurt, and you have to lie down. Your whole body feels bad, and it makes you hate everything. You feel like you're going to die but usually don't.

We say all life is made of bags, but these things aren't. They also can't make more of themselves; they have to get a bag to make them. So we don't know if it makes sense to say they're "alive." They're more like an idea that spreads itself.



Life Sciences Connection

Modeling Apoptosis When infected with pathogens such as bacteria or viruses, our bodies mount an immune response to fight the invaders. Part of this response includes generating and activating a large number of immune cells specifically to counteract the current threat. But once the bacteria or viruses have been eliminated, the remaining immune cells must be destroyed, too.

Using library and Internet resources, research how the body destroys excess immune cells after a successful immune response. Draw a model based on evidence to show the role apoptosis plays, and predict possible outcomes if too many or too few immune cells respond to apoptotic signals.

FIGURE 1: A cell undergoing apoptosis.

Art Connection

Virtual Agar Art Since 2015, the American Society of Microbiology has sponsored a public competition called "Agar Art." Scientists from around the world submit artworks created by culturing one or more bacterial or fungal species in nutrient agar on Petri dishes. The rate and color of the growth depend on the species, competition, and nutrients in the agar. With careful planning, the growth can result in an intricate work of art.

Using library and Internet resources, research art pieces made using agar. Make a poster or other presentation of your "agar art." Include multiple colors and indicate, based on your research, which species would contribute each color. Also explain how growth and reproduction contribute to the work, and identify factors you would need to consider in growing multiple species together.

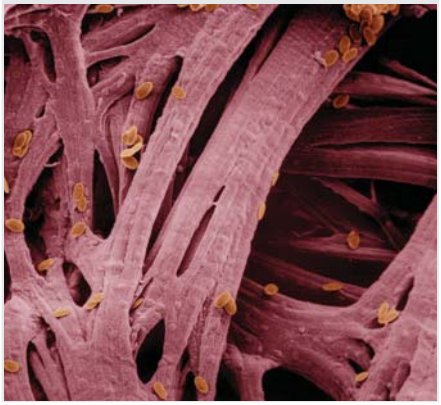
FIGURE 2: An Example of "Agar Art"

Medical Science Connection

Heart Regeneration In your body, some cell types—such as skin—can regenerate through cell division to replace lost or dead cells. Many other cell types lack this ability, however. Research suggested for many years that heart muscle is unable to regenerate after damage, and that heart cells lose the ability to divide at a young age. Recent studies have challenged this idea, hinting that some heart muscle cells may be able to divide following tissue damage, though at a very slow rate.

Locate and read at least three sources describing heart regeneration research, with at least one on either side of the debate. Summarize your findings in a report, and using evidence from the sources, give your opinion on whether heart muscle cells can regenerate in adult humans.

FIGURE 3: Heart Muscle



SYNTHESIZE THE UNIT

In your Evidence Notebook, make a concept map, graphic organizer, or outline using the Study Guides you made for each lesson in this unit. Be sure to use evidence to support your claims.

When synthesizing individual information, remember to follow these general steps:

- Find the central idea of each piece of information.
- Think about the relationships between the central ideas.
- Combine the ideas to come up with a new understanding.

DRIVING QUESTIONS

Look back to the Driving Questions from the opening section of this unit. In your Evidence Notebook, review and revise your previous answers to those questions. Use the evidence you gathered and other observations you made throughout the unit to support your claims.

PRACTICE AND REVIEW

1. In adults, the liver does not normally grow larger or regenerate cells. Based on this knowledge, most adult liver cells would be expected to:

a. regularly undergo mitosis

b. have highly condensed chromosomes

c. often replicate the cells' DNA

d. be in the interphase, or resting phase

2. As cells grow larger, what happens to the surface area-to-volume ratio? How does this affect the cell's ability to grow further?

3. Apoptosis, or programmed cell death, is triggered during which biological processes? Select all correct answers.

a. DNA damage suffered by a cell

b. a lymphocyte responding to an active infection

c. differentiation of a stem cell into a specialized cell

d. removal of certain tissues during embryonic development

4. Explain the connection between the cell cycle and cancer development.

5. Cyclins are proteins produced in cells only briefly, at specific stages of the cell cycle. These cyclins regulate the activity of kinase proteins, which help to move the cell to the next cell cycle phase. If regulation of cyclins or kinases is disrupted, the cell division process can go awry. In your Evidence Notebook, predict what might happen if cyclins were produced constantly throughout the cell cycle.

6. Telomeres are strings of repeating nucleotides that provide a "cap" on the ends of chromosomes. Though telomere sequences do not contain genes, why might they be important during an organism's life span?

a. Telomeres allow sister chromatids to join together.

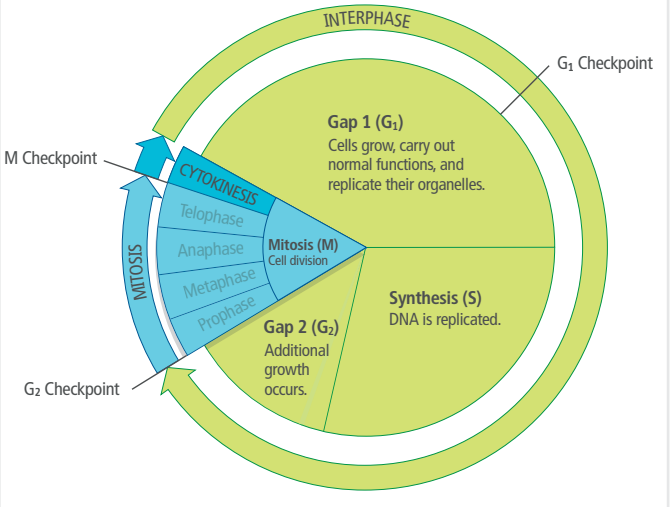
b. Telomeres prevent loss of genes when chromosomes are replicated.

c. Telomeres regulate the expression of other genes on the chromosome.

d. Telomeres increase the rate of cell division.

Use Figure 4 to answer question 7.

FIGURE 4: The Cell Cycle



7. Must the cell cycle always proceed in the same direction, or is it possible for the cycle to proceed in the opposite direction? Explain your reasoning.

8. Which of these best explains why stem cells can be used to treat some diseases such as leukemia, a cancer of white blood cells?

a. Stem cells do not age, and they can divide indefinitely.

b. Stem cells can differentiate into any type of cell.

c. Stem cells are able to adhere to damaged cells and initiate a repair sequence.

d. Stem cells contain a full set of chromosomes, unlike other cells in the body.

9. What are some of the advantages for organisms that undergo mitotic reproduction, as opposed to sexual reproduction? Select all correct answers.

a. Mitotic reproduction can occur without a partner.

b. Mitotic reproduction leads to offspring with greater genetic diversity.

c. Mitotic reproduction is faster than sexual reproduction.

d. Mitotic reproduction can allow a new organism to grow from a fragment of another.

10. Suppose an organism normally has 24 chromosomes. If a cell in this organism divides by mitosis, how many chromosomes should each daughter cell have after cell division occurs? Explain your answer.

11. Unlike stem cells, most body cells cannot form different types of cells. For example, skin cells can only make skin cells, and nerve cells only make nerve cells. Which statement best explains why skin cells would not become nerve cells?

a. Each type of cell gets a different message from the central DNA, which is stored in DNA cells.

b. Each type of cell has only the part of the DNA necessary for making that type of cell.

c. Each cell type is determined by messages sent from the brain, which directs development.

d. Both types of cells have the same DNA, but each cell uses only part of the DNA message.

12. Use the terms below to complete this statement explaining how mitosis produces two genetically identical cells.

condenses, spindle fibers, nuclear membrane, chromatin, cytokinesis, duplicated

During interphase, DNA is in a loosely arranged form called _____. Before a cell divides, each chromosome is _____ so that each daughter cell will have a complete set of DNA. As a cell progresses into prophase, the cell's DNA _____ to form tightly coiled chromosomes. In addition, the _____ breaks down, and centrioles begin to move to opposite poles of the cell. In metaphase, chromosomes align along the cell equator, and _____ attach to each chromosome. The chromosomes are separated in anaphase. In telophase, chromosomes begin to uncoil, and nuclear membranes begin to form. Finally, _____ divides the cytoplasm, producing two genetically identical daughter cells.

UNIT PROJECT

Return to your unit project. Prepare your research and materials into a presentation to share with the class. In your final presentation, evaluate the strength of your hypothesis, data, analysis, and conclusions.

Remember these tips while evaluating:

- Was your hypothesis supported by your data?
- Look at the empirical evidence—evidence based on observations and data. Does the evidence support your claim regarding the processes involved in the formation of a new plant?
- Consider if the explanation is logical. Does your research contradict any evidence you have seen?

Comparing Normal Cells and Cancer Cells

Cancer arises in cells due to abnormal genetic changes and can lead to other genetic, structural, and molecular alterations. Typically, the cell cycle of cancerous cells is disrupted compared with that of normal cells from the same tissue. The data shown here are from six different tissue samples. The samples were collected to determine whether the tissue in question contains cancerous cells. In this activity, your task is to analyze the data and make a claim for which samples are most likely to contain cancerous cells.

1. PLAN AN INVESTIGATION

With your team, formulate a plan for analyzing the data. Decide how you will compare the data, what calculations you will need to perform, and which type of graph would be best for displaying these data. You may want to make multiple graphs or sets of calculations to compare the data in multiple ways.

2. ANALYZE DATA

On your own, show the work for the calculations performed. Construct the necessary graph(s) based on what your group decided. You may use a computer program if necessary.

3. EVALUATE DATA

Based on your findings, which samples are more likely to contain cancerous cells? Compare your findings with the group. Are there any other patterns you can identify?

4. COMMUNICATE

Write a report explaining your conclusions, including a claim, evidence, and reasoning. Your claim should state which samples are most likely to contain cancerous cells, and you should explain, in detail, how your analysis of the data supports your claim. In addition, describe some of the factors that might have caused the cancerous cells to become cancerous. How is the cell cycle related to the development of these types of cells? How is a person's genetic material and external environment related to the development of cancer?

FIGURE 5: For each tissue sample, the number of cells in each phase were counted and recorded.

	Sample 1	Sample 2	Sample 3
Interphase	33	34	34
Prophase	2	2	1
Metaphase	1	3	2
Anaphase	2	2	2
Telophase	1	3	1

	Sample 4	Sample 5	Sample 6
Interphase	35	33	35
Prophase	3	3	3
Metaphase	1	2	2
Anaphase	0	2	4
Telophase	1	3	3

CHECK YOUR WORK

A complete presentation should include the following information:

- a clearly defined plan for analyzing and evaluating the data
- a clear conclusion based on evidence and supporting analysis
- one or more graphs displaying the data you evaluated in your investigation
- an explanation of which cells are most likely to be cancerous cells using evidence to support your claims