4 | CELL STRUCTURE

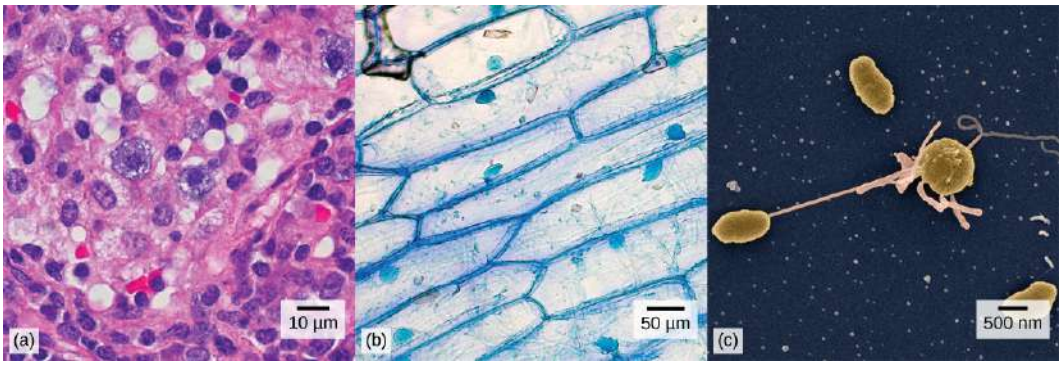


Figure 4.1 (a) Nasal sinus cells (viewed with a light microscope), (b) onion cells (viewed with a light microscope), and (c) *Vibrio tasmaniensis* bacterial cells (seen through a scanning electron microscope) are from very different organisms, yet all share certain characteristics of basic cell structure. (credit a: modification of work by Ed Uthman, MD; credit b: modification of work by Umberto Salvagnin; credit c: modification of work by Anthony D'Onofrio, William H. Fowle, Eric J. Stewart, and Kim Lewis of the Lewis Lab at Northeastern University; scale-bar data from Matt Russell)

Chapter Outline

Introduction

Close your eyes and picture a brick wall. What is the basic building block of that wall? A single brick, of course. Like a brick wall, your body is composed of basic building blocks called “cells.”

Your body has many kinds of cells, each specialized for a specific purpose. Just as a home is made from a variety of building materials, the human body is constructed from many cell types. For example, epithelial cells protect the surface of the body and cover the organs and body cavities within. Bone cells help to support and protect the body. Immune system cells fight invading pathogens. Additionally, blood cells carry nutrients and oxygen throughout the body while removing carbon dioxide and other waste. Each of these cell types plays a vital role during the growth, development, and ongoing maintenance of the body. In spite of their enormous variety, however, cells from all organisms—even organisms as diverse as bacteria, onion, and human—share certain fundamental characteristics.

In humans, before a cell develops into its specialized type, it is called a stem cell. A stem cell is a cell that has not undergone the changes involved in specialization. In this state, it may differentiate to become one of many different specialized cells, and it may divide to produce more stem cells. Under normal circumstances, once a cell becomes specialized, it remains that way. However, scientists have been working on coaxing stem cells in the laboratory to become a particular specialization. For example, scientists at the Cincinnati Children’s Hospital Medical Center have learned how to use stem cells to grow stomach tissue in plastic cell and tissue culture dishes. This accomplishment will enable researchers to study gastric human diseases, such as stomach cancer. You can read more about it **here (http://openstaxcollege.org/l/32cellsize)** .

4.1 | Studying Cells

In this section, you will explore the following questions:

- What is the role of cells in organisms?
- What is the difference between light microscopy and electron microscopy?
- What is the cell theory?

Connection for AP® Courses

A cell is the smallest unit of a living thing. A living thing, whether made of one cell (like bacteria) or many cells (like a human), is called an organism. Thus, cells are the basic building blocks of all organisms.

Several cells of one kind that interconnect with each other and perform a shared function form a tissue; several tissues combine to form an organ (your stomach, heart, or brain), and several organs make up an organ system (such as the digestive system, circulatory system, or nervous system). Several systems that function together form an organism (like a human being). Here, we will examine the structure and function of cells.

There are many types of cells, all grouped into one of two broad categories: prokaryotic and eukaryotic. For example, both animal and plant cells are classified as eukaryotic cells, whereas bacterial cells are classified as prokaryotic. Before discussing the criteria for determining whether a cell is prokaryotic or eukaryotic, let's first examine how biologists study cells.

Microscopy

Cells vary in size. With few exceptions, individual cells cannot be seen with the naked eye, so scientists use microscopes (micro- = "small"; -scope = "to look at") to study them. A **microscope** is an instrument that magnifies an object. Most photographs of cells are taken with a microscope, and these images can also be called micrographs.

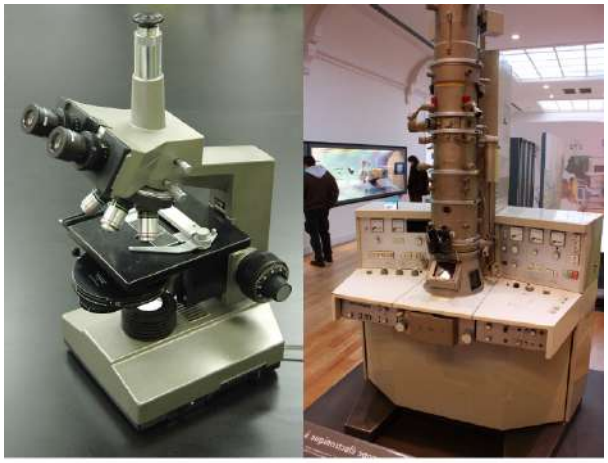
The optics of a compound microscope's lenses change the orientation of the image that the user sees. A specimen that is right-side up and facing right on the microscope slide will appear upside-down and facing left when viewed through a microscope, and vice versa. Similarly, if the slide is moved left while looking through the microscope, it will appear to move right, and if moved down, it will seem to move up. This occurs because microscopes use two sets of lenses to magnify the image. Because of the manner by which light travels through the lenses, this system of two lenses produces an inverted image (binocular, or dissecting microscopes, work in a similar manner, but include an additional magnification system that makes the final image appear to be upright).

Light Microscopes

To give you a sense of cell size, a typical human red blood cell is about eight millionths of a meter or eight micrometers (abbreviated as eight μm) in diameter; the head of a pin of is about two thousandths of a meter (two mm) in diameter. That means about 250 red blood cells could fit on the head of a pin.

Most student microscopes are classified as **light microscopes** (**Figure 4.2a**). Visible light passes and is bent through the lens system to enable the user to see the specimen. Light microscopes are advantageous for viewing living organisms, but since individual cells are generally transparent, their components are not distinguishable unless they are colored with special stains. Staining, however, usually kills the cells.

Light microscopes commonly used in the undergraduate college laboratory magnify up to approximately 400 times. Two parameters that are important in microscopy are magnification and resolving power. Magnification is the process of enlarging an object in appearance. Resolving power is the ability of a microscope to distinguish two adjacent structures as separate: the higher the resolution, the better the clarity and detail of the image. When oil immersion lenses are used for the study of small objects, magnification is usually increased to 1,000 times. In order to gain a better understanding of cellular structure and function, scientists typically use electron microscopes.



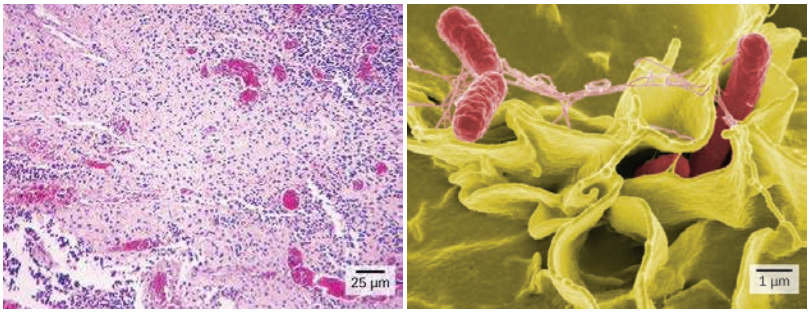
(a) (b)

Figure 4.2 (a) Most light microscopes used in a college biology lab can magnify cells up to approximately 400 times and have a resolution of about 200 nanometers. (b) Electron microscopes provide a much higher magnification, 100,000x, and a have a resolution of 50 picometers. (credit a: modification of work by "GcG"/Wikimedia Commons; credit b: modification of work by Evan Bench)

Electron Microscopes

In contrast to light microscopes, **electron microscopes** (**Figure 4.2b**) use a beam of electrons instead of a beam of light. Not only does this allow for higher magnification and, thus, more detail (**Figure 4.3**), it also provides higher resolving power. The method used to prepare the specimen for viewing with an electron microscope kills the specimen. Electrons have short wavelengths (shorter than photons) that move best in a vacuum, so living cells cannot be viewed with an electron microscope.

In a scanning electron microscope, a beam of electrons moves back and forth across a cell's surface, creating details of cell surface characteristics. In a transmission electron microscope, the electron beam penetrates the cell and provides details of a cell's internal structures. As you might imagine, electron microscopes are significantly more bulky and expensive than light microscopes.



(a) (b)

Figure 4.3 (a) These *Salmonella* bacteria appear as tiny purple dots when viewed with a light microscope. (b) This scanning electron microscope micrograph shows *Salmonella* bacteria (in red) invading human cells (yellow). Even though subfigure (b) shows a different *Salmonella* specimen than subfigure (a), you can still observe the comparative increase in magnification and detail. (credit a: modification of work by CDC/Armed Forces Institute of Pathology, Charles N. Farmer, Rocky Mountain Laboratories; credit b: modification of work by NIAID, NIH; scale-bar data from Matt Russell)

For another perspective on cell size, try the HowBig interactive at **this site (http://openstaxcollege.org/l/cell_sizes)** .

Why are electron microscopes crucial for the study of cell biology?

a. Only electron microscopes can be used to view internal structures.

b. Some electron microscopes allow visualization of three dimensional external shapes at very high magnification in a way that is not possible with standard light microscopes.

c. Scanning electron microscopes can show internal structures clearly at very high magnifications.

d. Electron microscopes are easier to use and less expensive than light microscopes.

Cell Theory

The microscopes we use today are far more complex than those used in the 1600s by Antony van Leeuwenhoek, a Dutch shopkeeper who had great skill in crafting lenses. Despite the limitations of his now-ancient lenses, van Leeuwenhoek observed the movements of single-celled organisms, which he collectively termed “animalcules.”

In a 1665 publication called *Micrographia*, experimental scientist Robert Hooke coined the term “cell” for the box-like structures he observed when viewing cork tissue through a lens. In the 1670s, van Leeuwenhoek discovered bacteria and protozoa. Later advances in lenses, microscope construction, and staining techniques enabled other scientists to see some components inside cells.

By the late 1830s, botanist Matthias Schleiden and zoologist Theodor Schwann were studying tissues and proposed the **unified cell theory**, which states that all living things are composed of one or more cells, the cell is the basic unit of life, and new cells arise from existing cells. Rudolf Virchow later made important contributions to this theory.

career CONNECTION

Have you ever heard of a medical test called a Pap smear (Figure 4.4)? In this test, a doctor takes a small sample of cells from the uterine cervix of a patient and sends it to a medical lab where a cytotechnologist stains the cells and examines them for any changes that could indicate abnormal cell growth or a microbial infection.

Cytotechnologists (cyto- = "cell") are professionals who study cells via microscopic examinations and other laboratory tests. They are trained to determine which cellular changes are within normal limits and which are abnormal. Their focus is not limited to cervical cells; they study cellular specimens that come from all organs. When they notice abnormalities, they consult a pathologist, who is a medical doctor who can make a clinical diagnosis.

Cytotechnologists play a vital role in saving people's lives. When abnormalities are discovered early, a patient's treatment can begin sooner, which usually increases the chances of a successful outcome.

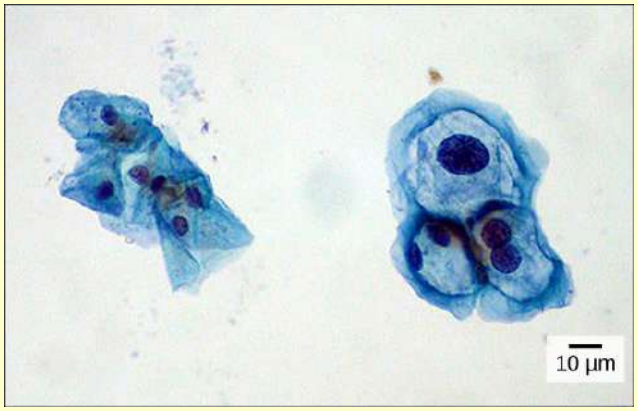


Figure 4.4 These uterine cervix cells, viewed through a light microscope, were obtained from a Pap smear. Normal cells are on the left. The cells on the right are infected with human papillomavirus (HPV). Notice that the infected cells are larger; also, two of these cells each have two nuclei instead of one, the normal number. (credit: modification of work by Ed Uthman, MD; scale-bar data from Matt Russell)

Section Summary

A cell is the smallest unit of life. Most cells are so tiny that they cannot be seen with the naked eye. Therefore, scientists use microscopes to study cells. Electron microscopes provide higher magnification, higher resolution, and more detail than light microscopes. The unified cell theory states that all organisms are composed of one or more cells, the cell is the basic unit of life, and new cells arise from existing cells.

4.2 | Prokaryotic Cells

In this section, you will explore the following questions:

- What are the major structures of prokaryotic cells?
- What limits the size of a cell?

Connection for AP® Courses

According to the cell theory, all living organisms, from bacteria to humans, are composed of cells, the smallest units of living matter. Often too small to be seen without a microscope, cells come in all sizes and shapes, and their small size allows for a large surface area-to-volume ratio that enables a more efficient exchange of nutrients and wastes with the environment.

There are three basic types of cells: archaea, bacteria, and eukaryotes. Both archaea and bacteria are classified as

prokaryotes, whereas cells of animals, plants, fungi, and protists are eukaryotes. Archaea are a unique group of organisms and likely evolved in the harsh conditions of early Earth and are still prevalent today in extreme environments, such as hot springs and polar regions. All cells share features that reflect their evolution from a common ancestor; these features are 1) a plasma membrane that separates the cell from its environment; 2) cytoplasm comprising the jelly-like cytosol inside the cell; 3) ribosomes that are important for the synthesis of proteins, and 4) DNA to store and transmit hereditary information.

Prokaryotes may also have a cell wall that acts as an extra layer of protection against the external environment. The term "prokaryote" means "before nucleus," and prokaryotes do not have nuclei. Rather, their DNA exists as a single circular chromosome in the central part of the cell called the nucleoid. Some bacterial cells also have circular DNA plasmids that often carry genes for resistance to antibiotics (Chapter 17). Other common prokaryotic cell features include flagella and pili.

The content presented in this section supports the learning objectives outlined in Big Idea 1 and Big Idea 2 of the AP® Biology Curriculum Framework. The AP® Learning Objectives merge essential knowledge content with one or more of the seven Science Practices. These objectives provide a transparent foundation for the AP® Biology course, along with inquiry-based laboratory experiences, instructional activities, and AP® exam questions.

Big Idea 1	The process of evolution drives the diversity and unity of life.
Enduring Understanding 1.D	The origin of living systems is explained by natural processes.
Essential Knowledge	**1.D.2** Scientific evidence from many different disciplines supports models of the origin of life.
Science Practice	**4.1** The student can justify the selection of the kind of data needed to answer a particular scientific question.
Learning Objective	**1.32** The student is able to justify the selection of geological, physical, chemical, and biological data that reveal early Earth conditions.
Essential Knowledge	**2.A.3** Organisms must exchange matter with the environment to grow, reproduce and maintain organization.
Science Practice	**2.2** The student can apply mathematical routines to quantities that describe natural phenomena.
Learning Objective	**2.6** The student is able to use calculated surface area-to-volume ratios to predict which cell(s) might eliminate wastes or procure nutrients faster by diffusion.
Essential Knowledge	**2.A.3** Organisms must exchange matter with the environment to grow, reproduce and maintain organization.
Science Practice	**6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	**2.7** The student will be able to explain how cell sizes and shapes affect the overall rate of nutrient intake and the rate of waste elimination.

Cells fall into one of two broad categories: prokaryotic and eukaryotic. Only the predominantly single-celled organisms of the domains Bacteria and Archaea are classified as prokaryotes (pro- = "before"; -kary- = "nucleus"). Cells of animals, plants, fungi, and protists are all eukaryotes (eu- = "true") and have a nucleus.

Components of Prokaryotic Cells

All cells share four common components: 1) a plasma membrane, an outer covering that separates the cell's interior from its surrounding environment; 2) cytoplasm, consisting of a jelly-like cytosol within the cell in which other cellular components are found; 3) DNA, the genetic material of the cell; and 4) ribosomes, which synthesize proteins. However, prokaryotes differ from eukaryotic cells in several ways.

A **prokaryote** is a simple, single-celled (unicellular) organism that lacks a nucleus, or any other membrane-bound organelle. We will shortly come to see that this is significantly different in eukaryotes. Prokaryotic DNA is found in a central part of the cell: the **nucleoid** (Figure 4.5).

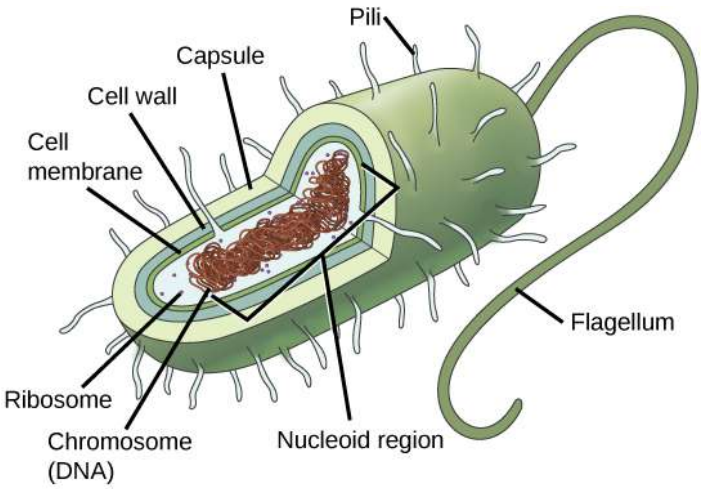


Figure 4.5 This figure shows the generalized structure of a prokaryotic cell. All prokaryotes have chromosomal DNA localized in a nucleoid, ribosomes, a cell membrane, and a cell wall. The other structures shown are present in some, but not all, bacteria.

everyday CONNECTION for AP® Courses

While the Earth is approximately 4.6 billion years old, the earliest fossil evidence for life are of microbial mats that date back to 3.5 billion years.

What type of evidence for life was most likely found in a 3.5 billion year old rock?

a. Scientists found bones buried in the rock that resemble bones of living animals.

b. Dead cells buried in the rock superficially resemble living prokaryotic cells.

c. The fossil superficially resembles living microbial mats that exist today.

d. Scientists found fossilized prokaryotic cells in the rock that are able to grow and divide.

Most prokaryotes have a peptidoglycan cell wall and many have a polysaccharide capsule (**Figure 4.5**). The cell wall acts as an extra layer of protection, helps the cell maintain its shape, and prevents dehydration. The capsule enables the cell to attach to surfaces in its environment. Some prokaryotes have flagella, pili, or fimbriae. Flagella are used for locomotion. Pili are used to exchange genetic material during a type of reproduction called conjugation. Fimbriae are used by bacteria to attach to a host cell.

career CONNECTION

Microbiologist

The most effective action anyone can take to prevent the spread of contagious illnesses is to wash his or her hands. Why? Because microbes (organisms so tiny that they can only be seen with microscopes) are ubiquitous. They live on doorknobs, money, your hands, and many other surfaces. If someone sneezes into his hand and touches a doorknob, and afterwards you touch that same doorknob, the microbes from the sneezer's mucus are now on your hands. If you touch your hands to your mouth, nose, or eyes, those microbes can enter your body and could make you sick.

However, not all microbes (also called microorganisms) cause disease; most are actually beneficial. You have microbes in your gut that make vitamin K.

Microbiologists are scientists who study microbes. Microbiologists can pursue a number of careers. Not only do they work in the food industry, they are also employed in the veterinary and medical fields. They can work in the pharmaceutical sector, serving key roles in research and development by identifying new sources of antibiotics that could be used to treat bacterial infections.

Environmental microbiologists may look for new ways to use specially selected or genetically engineered microbes for the removal of pollutants from soil or groundwater, as well as hazardous elements from contaminated sites. These uses of microbes are called bioremediation technologies. Microbiologists can also work in the field of bioinformatics, providing specialized knowledge and insight for the design, development, and specificity of computer models of, for example, bacterial epidemics.

Cell Size

At 0.1 to 5.0 μm in diameter, prokaryotic cells are significantly smaller than eukaryotic cells, which have diameters ranging from 10 to 100 μm (**Figure 4.6**). The small size of prokaryotes allows ions and organic molecules that enter them to quickly diffuse to other parts of the cell. Similarly, any wastes produced within a prokaryotic cell can quickly diffuse out. This is not the case in eukaryotic cells, which have developed different structural adaptations to enhance intracellular transport.

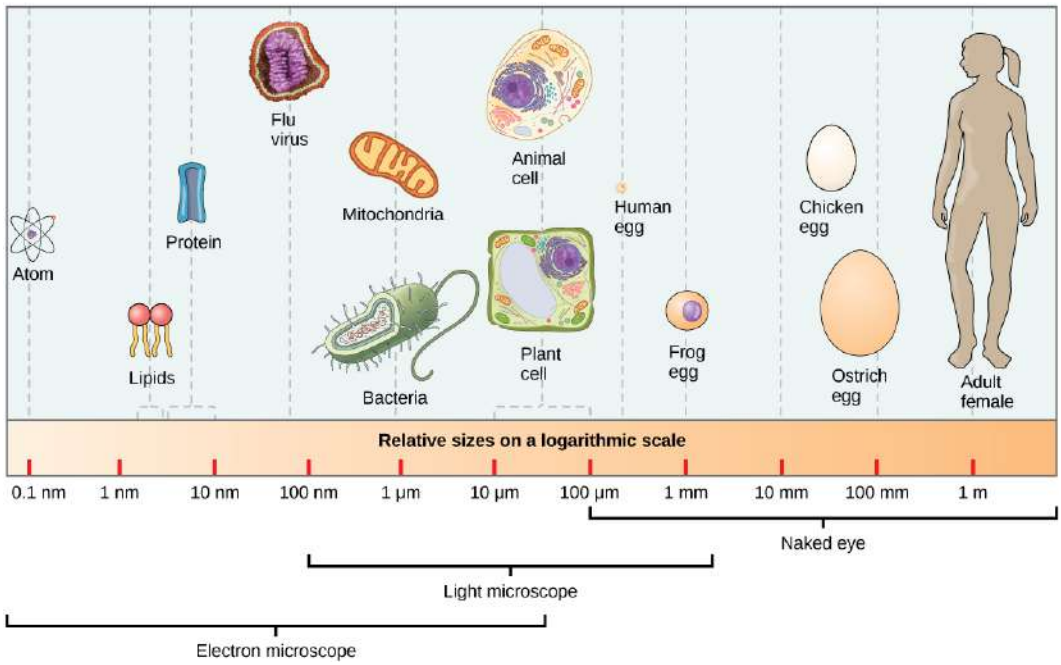


Figure 4.6 This figure shows relative sizes of microbes on a logarithmic scale (recall that each unit of increase in a logarithmic scale represents a 10-fold increase in the quantity being measured).

Small size, in general, is necessary for all cells, whether prokaryotic or eukaryotic. Let's examine why that is so. First, we'll consider the area and volume of a typical cell. Not all cells are spherical in shape, but most tend to approximate a

sphere. You may remember from your high school geometry course that the formula for the surface area of a sphere is $4\pi r^2$, while the formula for its volume is $4\pi r^3/3$. Thus, as the radius of a cell increases, its surface area increases as the square of its radius, but its volume increases as the cube of its radius (much more rapidly). Therefore, as a cell increases in size, its surface area-to-volume ratio decreases. This same principle would apply if the cell had the shape of a cube (**see this figure**). If the cell grows too large, the plasma membrane will not have sufficient surface area to support the rate of diffusion required for the increased volume. In other words, as a cell grows, it becomes less efficient. One way to become more efficient is to divide; another way is to develop organelles that perform specific tasks. These adaptations lead to the development of more sophisticated cells called eukaryotic cells.

Besides the volume of the cell, the size of the cell is also important for survival. As mentioned before, most cells are approximately spherical in shape. This is because a sphere is the shape with the largest surface area-to-volume ratio. As nutrients diffuse into the cell, a sphere is the shape where nutrients would have to travel the least distance to reach the center. This is important because nutrients and wastes are always exchanged at the periphery of the cell. The shorter the distance these nutrients and wastes have to travel, the faster the exchange of these molecules are.

visual CONNECTION

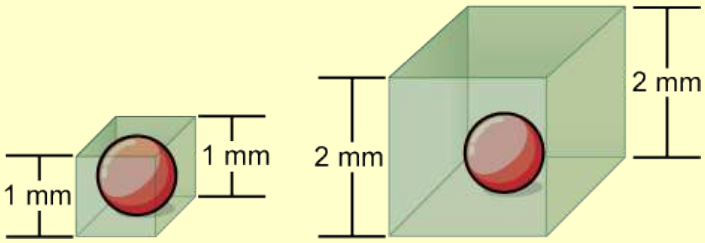


Figure 4.7 Notice that as a cell increases in size, its surface area-to-volume ratio decreases. When there is insufficient surface area to support a cell's increasing volume, a cell will either divide or die. The cell on the left has a volume of 1 mm^3 and a surface area of 6 mm^2, with a surface area-to-volume ratio of 6 to 1, whereas the cell on the right has a volume of 8 mm^3 and a surface area of 24 mm^2, with a surface area-to-volume ratio of 3 to 1.

On average, prokaryotic cells are smaller than eukaryotic cells. What are some advantages to small cell size? What are some advantages to large cell size?

a. Small, prokaryotic cells do not expend energy in intracellular transport of substances. Larger eukaryotic cells have organelles, which enable them to produce complex substances.

b. Small, prokaryotic cells easily escape the spontaneous changes in environmental conditions. Large, eukaryotic cells have complex mechanisms to cope with such changes.

c. Small, prokaryotic cells divide at a higher rate. Large, eukaryotic cells show division with genetic variations.

d. Small, prokaryotic cells have fewer phospholipids in their membrane. Large, eukaryotic cells have more transport proteins in their phospholipid bilayer, supporting efficient transport of molecules.

science practices CONNECTION for AP® Courses

Activity

Create an annotated diagram to explain how approximately 300 million alveoli in a human lung increases surface area for gas exchange to the size of a tennis court. Use the diagram to explain how the cellular structures of alveoli, capillaries, and red blood cells allow for rapid diffusion of O_2 and CO_2 among them.

Think About It

Which of the following cells would likely exchange nutrients and wastes with its environment more efficiently: a spherical cell with a diameter of 5 μm or a cubed-shaped cell with a side length of 7μm? Provide a quantitative justification for your answer based on surface area-to-volume ratios.

4.3 | Eukaryotic Cells

In this section, you will explore the following questions:

- How does the structure of the eukaryotic cell resemble as well as differ from the structure of the prokaryotic cell?
- What are structural differences between animal and plant cells?
- What are the functions of the major cell structures?

Connection for AP® Courses

Eukaryotic cells possess many features that prokaryotic cells lack, including a nucleus with a double membrane that encloses DNA. In addition, eukaryotic cells tend to be larger and have a variety of membrane-bound organelles that perform specific, compartmentalized functions. Evidence supports the hypothesis that eukaryotic cells likely evolved from prokaryotic ancestors; for example, mitochondria and chloroplasts feature characteristics of independently-living prokaryotes. Eukaryotic cells come in all shapes, sizes, and types (e.g. animal cells, plant cells, and different types of cells in the body). (Hint: This a rare instance where you should create a list of organelles and their respective functions because later you will focus on how various organelles work together, similar to how your body's organs work together to keep you healthy.) Like prokaryotes, all eukaryotic cells have a plasma membrane, cytoplasm, ribosomes, and DNA. Many organelles are bound by membranes composed of phospholipid bilayers embedded with proteins to compartmentalize functions such as the storage of hydrolytic enzymes and the synthesis of proteins. The nucleus houses DNA, and the nucleolus within the nucleus is the site of ribosome assembly. Functional ribosomes are found either free in the cytoplasm or attached to the rough endoplasmic reticulum where they perform protein synthesis. The Golgi apparatus receives, modifies, and packages small molecules like lipids and proteins for distribution. Mitochondria and chloroplasts participate in free energy capture and transfer through the processes of cellular respiration and photosynthesis, respectively. Peroxisomes oxidize fatty acids and amino acids, and they are equipped to break down hydrogen peroxide formed from these reactions without letting it into the cytoplasm where it can cause damage. Vesicles and vacuoles store substances, and in plant cells, the central vacuole stores pigments, salts, minerals, nutrients, proteins, and degradation enzymes and helps maintain rigidity. In contrast, animal cells have centrosomes and lysosomes but lack cell walls.

Information presented and the examples highlighted in the section support concepts and Learning Objectives outlined in Big Idea 1, Big Idea 2, and Big Idea 4 of the AP® Biology Curriculum Framework. The Learning Objectives listed in the Curriculum Framework provide a transparent foundation for the AP® Biology course, an inquiry-based laboratory experience, instructional activities, and AP® exam questions. A Learning Objective merges required content with one or more of the seven Science Practices.

Big Idea 1	The process of evolution drives the diversity and unity of life.

Enduring Understanding 1.B	Organisms are linked by lines of descent from common ancestry
Essential Knowledge	**1.B.1** Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.
Science Practice	**7.2** The student can connect concepts in and across domains to generalize or extrapolate in and/or across enduring understandings
Learning Objective	**1.15** The student is able to describe specific examples of conserved core biological processes and features shared by all domains or within one domain of life and how these shared, conserved core processes and features support the concept of common ancestry for all organisms.
Big Idea 2	Biological systems utilize free energy and molecular building blocks to grow, to reproduce and to maintain dynamic homeostasis.
Enduring Understanding 2.B	Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.
Essential Knowledge	**2.B.3** Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.
Science Practice	**6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	**2.13** The student is able to explain how internal membranes and organelles contribute to cell functions.
Essential Knowledge	**2.B.3** Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.
Science Practice	**1.4** The student can use representations and models to analyze situations or solve problems qualitatively and quantitatively.
Learning Objective	**2.14** The student is able to use representations and models to describe differences in prokaryotic and eukaryotic cells.
Big Idea 4	Biological systems interact, and these systems and their interactions possess complex properties.
Enduring Understanding 4.A	Interactions within biological systems lead to complex properties.
Essential Knowledge	**4.A.2** The structure and function of subcellular components, and their interactions, provide essential cellular processes.
Science Practice	**6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	**4.5** The student is able to construct explanations based on scientific evidence as to how interactions of subcellular structures provide essential functions.

The Science Practice Challenge Questions contain additional test questions for this section that will help you prepare for the AP exam. These questions address the following standards:
[APLO 1.15] [APLO 2.5][APLO 2.25][APLO 1.16]

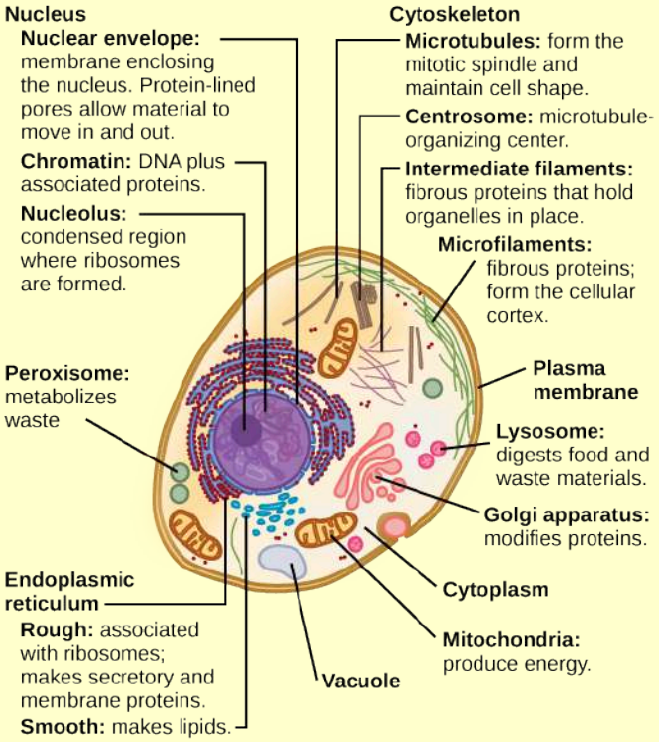
Have you ever heard the phrase “form follows function?” It’s a philosophy practiced in many industries. In architecture, this means that buildings should be constructed to support the activities that will be carried out inside them. For example, a skyscraper should be built with several elevator banks; a hospital should be built so that its emergency room is easily accessible.

Our natural world also utilizes the principle of form following function, especially in cell biology, and this will become clear

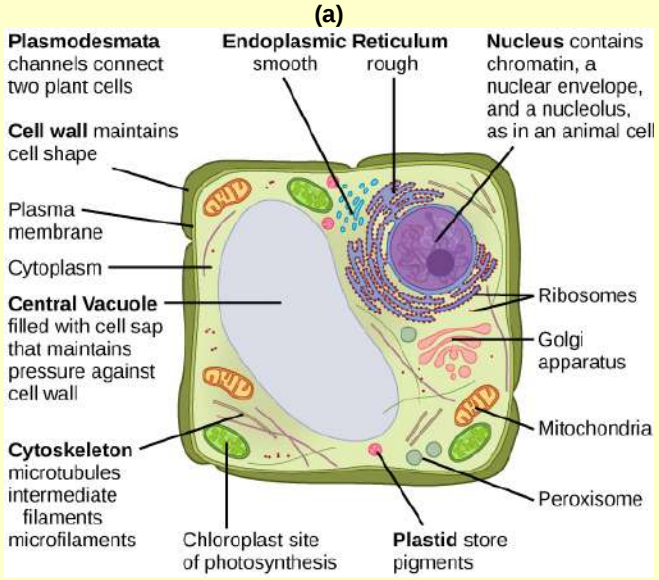
as we explore eukaryotic cells (**Figure 4.8**). Unlike prokaryotic cells, **eukaryotic cells** have: 1) a membrane-bound nucleus; 2) numerous membrane-bound **organelles** such as the endoplasmic reticulum, Golgi apparatus, chloroplasts, mitochondria, and others; and 3) several, rod-shaped chromosomes. Because a eukaryotic cell's nucleus is surrounded by a membrane, it is often said to have a "true nucleus." The word "organelle" means "little organ," and, as already mentioned, organelles have specialized cellular functions, just as the organs of your body have specialized functions.

At this point, it should be clear to you that eukaryotic cells have a more complex structure than prokaryotic cells. Organelles allow different functions to be compartmentalized in different areas of the cell. Before turning to organelles, let's first examine two important components of the cell: the plasma membrane and the cytoplasm.

visual CONNECTION



(a)



(b)

Figure 4.8 These figures show the major organelles and other cell components of (a) a typical animal cell and (b) a typical eukaryotic plant cell. The plant cell has a cell wall, chloroplasts, plastids, and a central vacuole—structures not found in animal cells. Most plant cells do not have lysosomes or centrosomes.

If the nucleolus were not able to carry out its function, what other cellular organelles would be affected?

a. The structure of endoplasmic reticulum would not form.

b. The function of lysosomes would be hindered, as hydrolases are formed by nucleolus.

c. The free ribosomes and the rough endoplasmic reticulum, which contains ribosomes, would not form.

d. The Golgi apparatus will not be able to sort proteins properly.

The Plasma Membrane

Like prokaryotes, eukaryotic cells have a **plasma membrane** (Figure 4.9), a phospholipid bilayer with embedded proteins that separates the internal contents of the cell from its surrounding environment. A phospholipid is a lipid molecule with two fatty acid chains and a phosphate-containing group. The plasma membrane controls the passage of organic molecules, ions, water, and oxygen into and out of the cell. Wastes (such as carbon dioxide and ammonia) also leave the cell by passing through the plasma membrane.

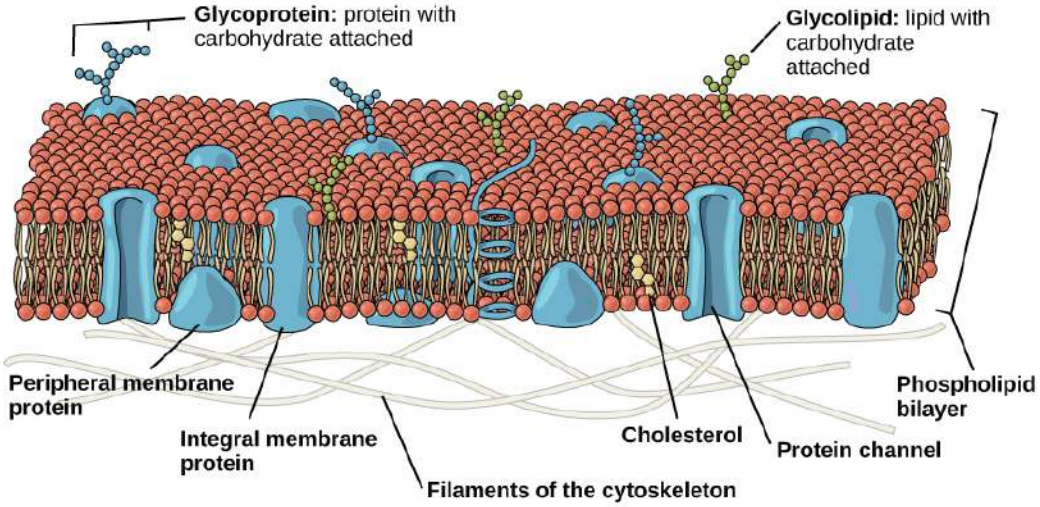


Figure 4.9 The eukaryotic plasma membrane is a phospholipid bilayer with proteins and cholesterol embedded in it.

The plasma membranes of cells that specialize in absorption are folded into fingerlike projections called microvilli (singular = microvillus); (Figure 4.10). Such cells are typically found lining the small intestine, the organ that absorbs nutrients from digested food. This is an excellent example of form following function. People with celiac disease have an immune response to gluten, which is a protein found in wheat, barley, and rye. The immune response damages microvilli, and thus, afflicted individuals cannot absorb nutrients. This leads to malnutrition, cramping, and diarrhea. Patients suffering from celiac disease must follow a gluten-free diet.

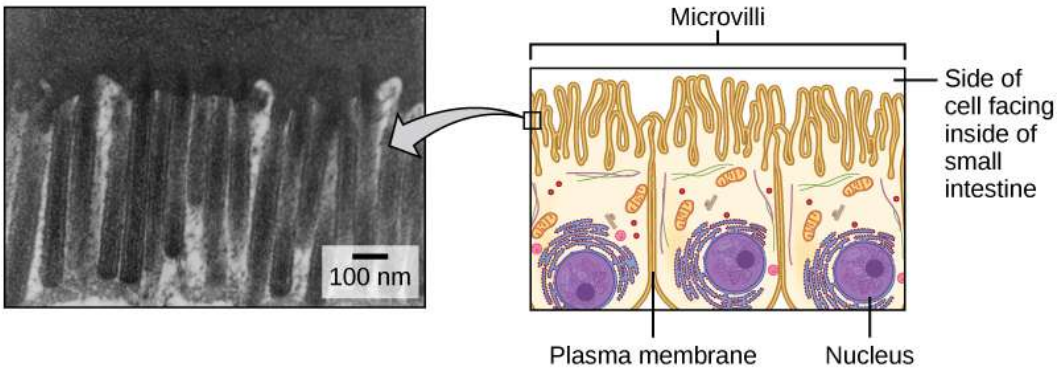


Figure 4.10 Microvilli, shown here as they appear on cells lining the small intestine, increase the surface area available for absorption. These microvilli are only found on the area of the plasma membrane that faces the cavity from which substances will be absorbed. (credit "micrograph": modification of work by Louisa Howard)

The Cytoplasm

The **cytoplasm** is the entire region of a cell between the plasma membrane and the nuclear envelope (a structure to be discussed shortly). It is made up of organelles suspended in the gel-like **cytosol**, the cytoskeleton, and various chemicals (Figure 4.8). Even though the cytoplasm consists of 70 to 80 percent water, it has a semi-solid consistency, which comes from the proteins within it. However, proteins are not the only organic molecules found in the cytoplasm. Glucose and other

simple sugars, polysaccharides, amino acids, nucleic acids, fatty acids, and derivatives of glycerol are found there, too. Ions of sodium, potassium, calcium, and many other elements are also dissolved in the cytoplasm. Many metabolic reactions, including protein synthesis, take place in the cytoplasm.

The Nucleus

Typically, the nucleus is the most prominent organelle in a cell (Figure 4.8). The **nucleus** (plural = nuclei) houses the cell's DNA and directs the synthesis of ribosomes and proteins. Let's look at it in more detail (Figure 4.11).

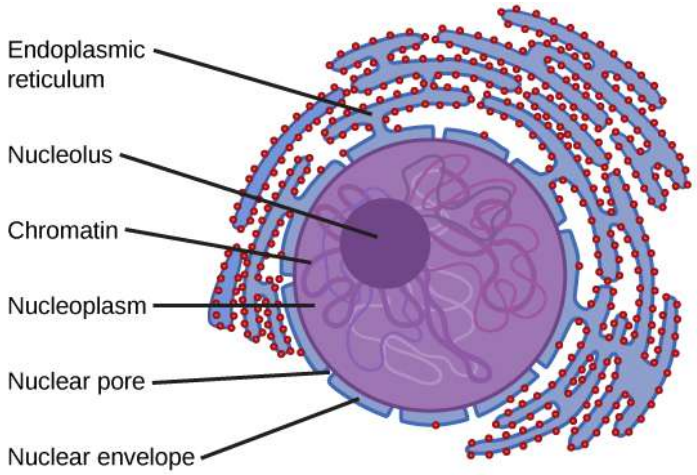


Figure 4.11 The nucleus stores chromatin (DNA plus proteins) in a gel-like substance called the nucleoplasm. The nucleolus is a condensed region of chromatin where ribosome synthesis occurs. The boundary of the nucleus is called the nuclear envelope. It consists of two phospholipid bilayers: an outer membrane and an inner membrane. The nuclear membrane is continuous with the endoplasmic reticulum. Nuclear pores allow substances to enter and exit the nucleus.

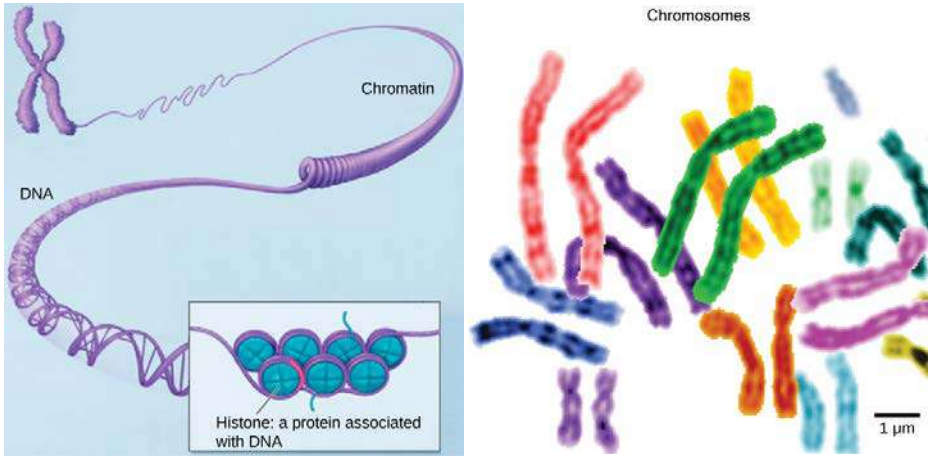
The Nuclear Envelope

The **nuclear envelope** is a double-membrane structure that constitutes the outermost portion of the nucleus (Figure 4.11). Both the inner and outer membranes of the nuclear envelope are phospholipid bilayers.

The nuclear envelope is punctuated with pores that control the passage of ions, molecules, and RNA between the nucleoplasm and cytoplasm. The **nucleoplasm** is the semi-solid fluid inside the nucleus, where we find the chromatin and the nucleolus.

Chromatin and Chromosomes

To understand chromatin, it is helpful to first consider chromosomes. **Chromosomes** are structures within the nucleus that are made up of DNA, the hereditary material. You may remember that in prokaryotes, DNA is organized into a single circular chromosome. In eukaryotes, chromosomes are linear structures. Every eukaryotic species has a specific number of chromosomes in the nucleus of each cell. For example, in humans, the chromosome number is 46, while in fruit flies, it is eight. Chromosomes are only visible and distinguishable from one another when the cell is getting ready to divide. When the cell is in the growth and maintenance phases of its life cycle, proteins are attached to chromosomes, and they resemble an unwound, jumbled bunch of threads. These unwound protein-chromosome complexes are called **chromatin** (Figure 4.12); chromatin describes the material that makes up the chromosomes both when condensed and decondensed.



(a) (b)

Figure 4.12 (a) This image shows various levels of the organization of chromatin (DNA and protein). (b) This image shows paired chromosomes. (credit b: modification of work by NIH; scale-bar data from Matt Russell)

The Nucleolus

We already know that the nucleus directs the synthesis of ribosomes, but how does it do this? Some chromosomes have sections of DNA that encode ribosomal RNA. A darkly staining area within the nucleus called the **nucleolus** (plural = nucleoli) aggregates the ribosomal RNA with associated proteins to assemble the ribosomal subunits that are then transported out through the pores in the nuclear envelope to the cytoplasm.

Ribosomes

Ribosomes are the cellular structures responsible for protein synthesis. When viewed through an electron microscope, ribosomes appear either as clusters (polyribosomes) or single, tiny dots that float freely in the cytoplasm. They may be attached to the cytoplasmic side of the plasma membrane or the cytoplasmic side of the endoplasmic reticulum and the outer membrane of the nuclear envelope (**Figure 4.8**). Electron microscopy has shown us that ribosomes, which are large complexes of protein and RNA, consist of two subunits, aptly called large and small (**Figure 4.13**). Ribosomes receive their "orders" for protein synthesis from the nucleus where the DNA is transcribed into messenger RNA (mRNA). The mRNA travels to the ribosomes, which translate the code provided by the sequence of the nitrogenous bases in the mRNA into a specific order of amino acids in a protein. Amino acids are the building blocks of proteins.

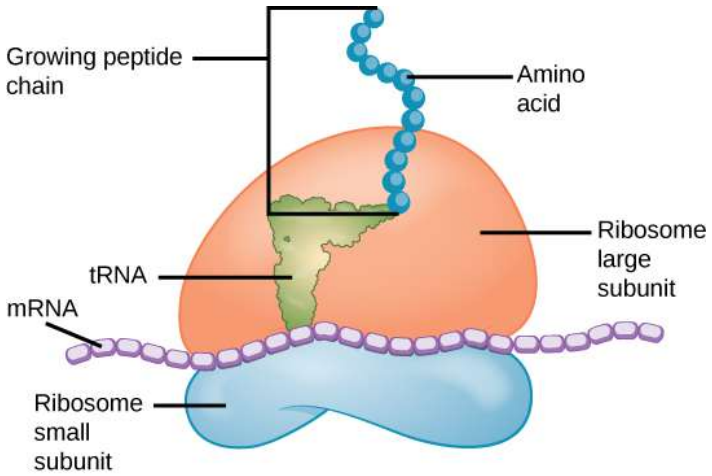


Figure 4.13 Ribosomes are made up of a large subunit (top) and a small subunit (bottom). During protein synthesis, ribosomes assemble amino acids into proteins.

Because protein synthesis is an essential function of all cells (including enzymes, hormones, antibodies, pigments, structural components, and surface receptors), ribosomes are found in practically every cell. Ribosomes are particularly abundant in cells that synthesize large amounts of protein. For example, the pancreas is responsible for creating several digestive enzymes and the cells that produce these enzymes contain many ribosomes. Thus, we see another example of form following function.

Mitochondria

Mitochondria (singular = mitochondrion) are often called the “powerhouses” or “energy factories” of a cell because they are responsible for making adenosine triphosphate (ATP), the cell’s main energy-carrying molecule. ATP represents the short-term stored energy of the cell. Cellular respiration is the process of making ATP using the chemical energy found in glucose and other nutrients. In mitochondria, this process uses oxygen and produces carbon dioxide as a waste product. In fact, the carbon dioxide that you exhale with every breath comes from the cellular reactions that produce carbon dioxide as a byproduct.

In keeping with our theme of form following function, it is important to point out that muscle cells have a very high concentration of mitochondria that produce ATP. Your muscle cells need a lot of energy to keep your body moving. When your cells don’t get enough oxygen, they do not make a lot of ATP. Instead, the small amount of ATP they make in the absence of oxygen is accompanied by the production of lactic acid.

Mitochondria are oval-shaped, double membrane organelles (Figure 4.14) that have their own ribosomes and DNA. Each membrane is a phospholipid bilayer embedded with proteins. The inner layer has folds called cristae. The area surrounded by the folds is called the mitochondrial matrix. The cristae and the matrix have different roles in cellular respiration.

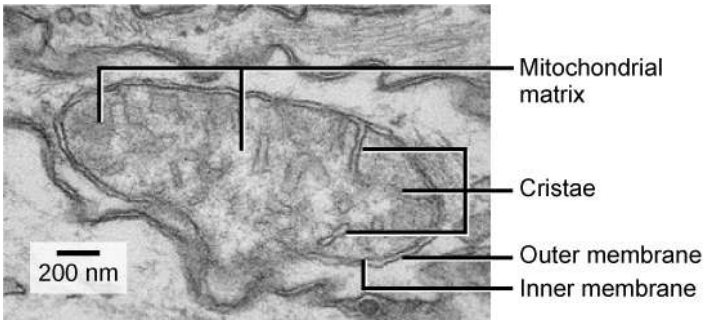


Figure 4.14 This electron micrograph shows a mitochondrion as viewed with a transmission electron microscope. This organelle has an outer membrane and an inner membrane. The inner membrane contains folds, called cristae, which increase its surface area. The space between the two membranes is called the intermembrane space, and the space inside the inner membrane is called the mitochondrial matrix. ATP synthesis takes place on the inner membrane. (credit: modification of work by Matthew Britton; scale-bar data from Matt Russell)

Peroxisomes

Peroxisomes are small, round organelles enclosed by single membranes. They carry out oxidation reactions that break down fatty acids and amino acids. They also detoxify many poisons that may enter the body. (Many of these oxidation reactions release hydrogen peroxide, H_2O_2, which would be damaging to cells; however, when these reactions are confined to peroxisomes, enzymes safely break down the H_2O_2 into oxygen and water.) Glyoxysomes, which are specialized peroxisomes in plants, are responsible for converting stored fats into sugars.

Vesicles and Vacuoles

Vesicles and **vacuoles** are membrane-bound sacs that function in storage and transport. Other than the fact that vacuoles are somewhat larger than vesicles, there is a very subtle distinction between them: The membranes of vesicles can fuse with either the plasma membrane or other membrane systems within the cell. Additionally, some agents such as enzymes within plant vacuoles break down macromolecules. The membrane of a vacuole does not fuse with the membranes of other cellular components.

Animal Cells versus Plant Cells

At this point, you know that each eukaryotic cell has a plasma membrane, cytoplasm, a nucleus, ribosomes, mitochondria, peroxisomes, and in some, vacuoles, but there are some striking differences between animal and plant cells. While both animal and plant cells have microtubule organizing centers (MTOCs), animal cells also have centrioles associated with the MTOC: a complex called the centrosome. Animal cells each have a centrosome and lysosomes, whereas most plant cells do not. Plant cells have a cell wall, chloroplasts and other specialized plastids, and a large central vacuole, whereas animal cells do not.

The Centrosome

The **centrosome** is a microtubule-organizing center found near the nuclei of animal cells. It contains a pair of centrioles, two structures that lie perpendicular to each other (Figure 4.15). Each centriole is a cylinder of nine triplets of microtubules.

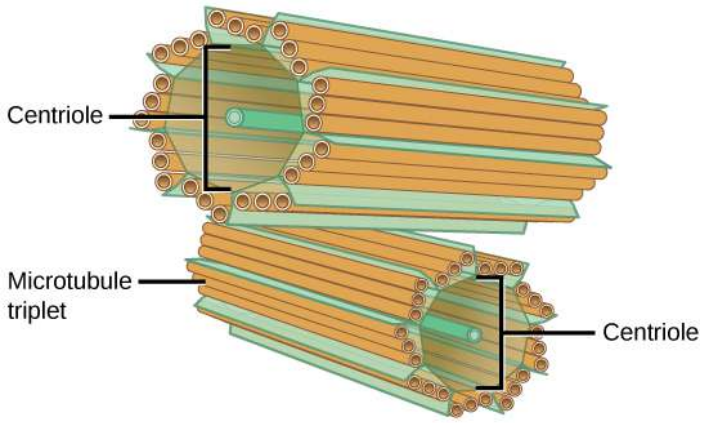


Figure 4.15 The centrosome consists of two centrioles that lie at right angles to each other. Each centriole is a cylinder made up of nine triplets of microtubules. Nontubulin proteins (indicated by the green lines) hold the microtubule triplets together.

The centrosome (the organelle where all microtubules originate) replicates itself before a cell divides, and the centrioles appear to have some role in pulling the duplicated chromosomes to opposite ends of the dividing cell. However, the exact function of the centrioles in cell division isn't clear, because cells that have had the centrosome removed can still divide, and plant cells, which lack centrosomes, are capable of cell division.

Lysosomes

Animal cells have another set of organelles not found in most plant cells: lysosomes. The **lysosomes** are the cell's "garbage disposal." In plant cells, the digestive processes take place in vacuoles. Enzymes within the lysosomes aid the breakdown of proteins, polysaccharides, lipids, nucleic acids, and even worn-out organelles. These enzymes are active at a much lower pH than that of the cytoplasm. Therefore, the pH within lysosomes is more acidic than the pH of the cytoplasm. Many reactions that take place in the cytoplasm could not occur at a low pH, so again, the advantage of compartmentalizing the eukaryotic cell into organelles is apparent.

The Cell Wall

If you examine **Figure 4.8b**, the diagram of a plant cell, you will see a structure external to the plasma membrane called the cell wall. The **cell wall** is a rigid covering that protects the cell, provides structural support, and gives shape to the cell. Fungal and protistan cells also have cell walls. While the chief component of prokaryotic cell walls is peptidoglycan, the major organic molecule in the plant cell wall is cellulose (**Figure 4.16**), a polysaccharide made up of glucose units. Have you ever noticed that when you bite into a raw vegetable, like celery, it crunches? That's because you are tearing the rigid cell walls of the celery cells with your teeth.

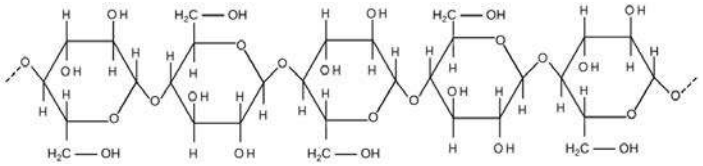


Figure 4.16 Cellulose is a long chain of β-glucose molecules connected by a 1-4 linkage. The dashed lines at each end of the figure indicate a series of many more glucose units. The size of the page makes it impossible to portray an entire cellulose molecule.

Chloroplasts

Like the mitochondria, chloroplasts have their own DNA and ribosomes, but chloroplasts have an entirely different function. **Chloroplasts** are plant cell organelles that carry out photosynthesis. Photosynthesis is the series of reactions that use carbon dioxide, water, and light energy to make glucose and oxygen. This is a major difference between plants and animals; plants (autotrophs) are able to make their own food, like sugars, while animals (heterotrophs) must ingest their food.

Like mitochondria, chloroplasts have outer and inner membranes, but within the space enclosed by a chloroplast's inner membrane is a set of interconnected and stacked fluid-filled membrane sacs called thylakoids (**Figure 4.17**). Each stack of thylakoids is called a granum (plural = grana). The fluid enclosed by the inner membrane that surrounds the grana is called the stroma.

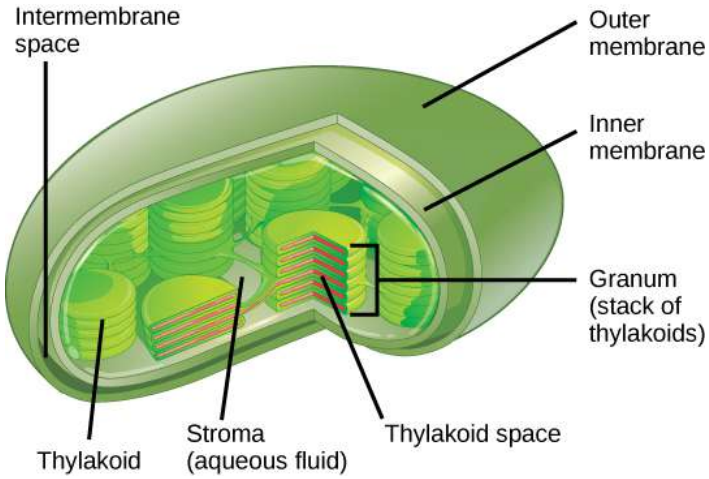


Figure 4.17 The chloroplast has an outer membrane, an inner membrane, and membrane structures called thylakoids that are stacked into grana. The space inside the thylakoid membranes is called the thylakoid space. The light harvesting reactions take place in the thylakoid membranes, and the synthesis of sugar takes place in the fluid inside the inner membrane, which is called the stroma. Chloroplasts also have their own genome, which is contained on a single circular chromosome.

The chloroplasts contain a green pigment called **chlorophyll**, which captures the light energy that drives the reactions of photosynthesis. Like plant cells, photosynthetic protists also have chloroplasts. Some bacteria perform photosynthesis, but their chlorophyll is not relegated to an organelle.

evolution CONNECTION

Endosymbiosis

We have mentioned that both mitochondria and chloroplasts contain DNA and ribosomes. Have you wondered why? Strong evidence points to endosymbiosis as the explanation.

Symbiosis is a relationship in which organisms from two separate species depend on each other for their survival. Endosymbiosis (endo- = “within”) is a mutually beneficial relationship in which one organism lives inside the other. Endosymbiotic relationships abound in nature. We have already mentioned that microbes that produce vitamin K live inside the human gut. This relationship is beneficial for us because we are unable to synthesize vitamin K. It is also beneficial for the microbes because they are protected from other organisms and from drying out, and they receive abundant food from the environment of the large intestine.

Scientists have long noticed that bacteria, mitochondria, and chloroplasts are similar in size. We also know that bacteria have DNA and ribosomes, just as mitochondria and chloroplasts do. Scientists believe that host cells and bacteria formed an endosymbiotic relationship when the host cells ingested both aerobic and autotrophic bacteria (cyanobacteria) but did not destroy them. Through many millions of years of evolution, these ingested bacteria became more specialized in their functions, with the aerobic bacteria becoming mitochondria and the autotrophic bacteria becoming chloroplasts.

Based on what you know about plant and animals cells, which of the following events are most likely to have occurred?

a. A host cell that ingested aerobic bacteria gave rise to modern animals, while ancestor of that cell that also ingested photoautotrophic bacteria that gave rise to modern plants.

b. A host cell that gave rise to modern plants ingested photoautotrophic bacteria only, while a host cell that gave rise to modern animals ingested aerobic bacteria only.

c. A host cell that gave rise to modern plants ingested both aerobic and photoautotrophic bacteria, while a host cell that gave rise to modern animals ingested photoautotrophic bacteria only.

d. A host cell that gave rise to modern plants and animals ingested both aerobic and photoautotrophic bacteria.

The Central Vacuole

Previously, we mentioned vacuoles as essential components of plant cells. If you look at **Figure 4.8b**, you will see that plant cells each have a large central vacuole that occupies most of the area of the cell. The **central vacuole** plays a key role in regulating the cell's concentration of water in changing environmental conditions. Have you ever noticed that if you forget to water a plant for a few days, it wilts? That's because as the water concentration in the soil becomes lower than the water concentration in the plant, water moves out of the central vacuoles and cytoplasm. As the central vacuole shrinks, it leaves the cell wall unsupported. This loss of support to the cell walls of plant cells results in the wilted appearance of the plant.

The central vacuole also supports the expansion of the cell. When the central vacuole holds more water, the cell gets larger without having to invest a lot of energy in synthesizing new cytoplasm.

science practices CONNECTION for AP® Courses

Activity

- Construct a concept map or Venn diagram to describe the relationships that exist among the three domains of life (Archaea, Bacteria, and Eukarya) based on cellular features. Share your diagram with other students in the class for review and revision.
- Mystery Cell ID. Using a microscope, identify several types of cells, e.g., prokaryote/eukaryote, plant/animal, based on general features and justify your identification.
- Ten-Minute Debate. Working in small teams, create a visual representation to support the claim that eukaryotes evolved from symbiotic relationships among groups of prokaryotes.

Think About It

- If the nucleolus were not able to carry out its function, what other cellular organelles would be affected? Would a human liver cell that lacked endoplasmic reticulum be able to metabolize toxins?
- Antibiotics are medicines that are used to fight bacterial infections. These medicines kill prokaryotic cells without harming human cells. What part(s) of the bacterial cell do antibiotics target and provide reasoning for your answer.

Section Summary

Like a prokaryotic cell, a eukaryotic cell has a plasma membrane, cytoplasm, and ribosomes, but a eukaryotic cell is typically larger than a prokaryotic cell, has a true nucleus (meaning its DNA is surrounded by a membrane), and has other membrane-bound organelles that allow for compartmentalization of functions. The plasma membrane is a phospholipid bilayer embedded with proteins. The nucleus's nucleolus is the site of ribosome assembly. Ribosomes are either found in the cytoplasm or attached to the cytoplasmic side of the plasma membrane or endoplasmic reticulum. They perform protein synthesis. Mitochondria participate in cellular respiration; they are responsible for the majority of ATP produced in the cell. Peroxisomes hydrolyze fatty acids, amino acids, and some toxins. Vesicles and vacuoles are storage and transport compartments. In plant cells, vacuoles also help break down macromolecules.

Animal cells also have a centrosome and lysosomes. The centrosome has two bodies perpendicular to each other, the centrioles, and has an unknown purpose in cell division. Lysosomes are the digestive organelles of animal cells.

Plant cells and plant-like cells each have a cell wall, chloroplasts, and a central vacuole. The plant cell wall, whose primary component is cellulose, protects the cell, provides structural support, and gives shape to the cell. Photosynthesis takes place in chloroplasts. The central vacuole can expand without having to produce more cytoplasm.

4.4 | The Endomembrane System and Proteins

In this section, you will explore the following questions:

- What is the relationship between the structure and function of the components of the endomembrane system, especially with regard to the synthesis of proteins?

Connection for AP® Courses

In addition to the presence of nuclei, eukaryotic cells are distinguished by an endomembrane system that includes the plasma membrane, nuclear envelope, lysosomes, vesicles, endoplasmic reticulum, and Golgi apparatus. These subcellular components work together to modify, tag, package, and transport proteins and lipids. The rough endoplasmic reticulum (RER) with its attached ribosomes is the site of protein synthesis and modification. The smooth endoplasmic reticulum (SER) synthesizes carbohydrates, lipids including phospholipids and cholesterol, and steroid hormones; engages in the detoxification of medications and poisons; and stores calcium ions. Lysosomes digest macromolecules, recycle worn-out organelles, and destroy pathogens. Just like your body uses different organs that work together, cells use these organelles interact to perform specific functions. For example, proteins that are synthesized in the RER then travel to the Golgi apparatus for modification and packaging for either storage or transport. If these proteins are hydrolytic enzymes, they can be stored in lysosomes. Mitochondria produce the energy needed for these processes. This functional flow through several organelles, a process which is dependent on energy produced by yet another organelle, serves as a hallmark illustration of the cell's complex, interconnected dependence on its organelles.

Information presented and the examples highlighted in the section support concepts and Learning Objectives outlined in Big Idea 2 and Big Idea 4 of the AP® Biology Curriculum Framework. The Learning Objectives listed in the Curriculum Framework provide a transparent foundation for the AP® Biology course, an inquiry-based laboratory experience, instructional activities, and AP® exam questions. A Learning Objective merges required content with one or more of the seven Science Practices.

Big Idea 2	Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis.
Enduring Understanding 2.B	Growth, reproduction and dynamic homeostasis require that cells create and maintain internal environments that are different from their external environments.
Essential Knowledge	**2.B.3** Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.
Science Practice	**6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	**2.13** The student is able to explain how internal membranes and organelles contribute to cell functions.
Big Idea 4	Biological systems interact, and these systems and their interactions possess complex properties.
Enduring Understanding 4.A	Interactions within biological systems lead to complex properties.
Essential Knowledge	**4.A.2** The structure and function of subcellular components, and their interactions, provide essential cellular processes.
Science Practice	**6.2** The student can construct explanations of phenomena based on evidence produced through scientific practices.
Learning Objective	**4.5** The student is able to construct explanations based on scientific evidence as to how interactions of subcellular structures provide essential functions.

The Science Practice Challenge Questions contain additional test questions for this section that will help you prepare for the AP exam. These questions address the following standards:
[APLO 4.6]

The Endoplasmic Reticulum

The endomembrane system (endo = "within") is a group of membranes and organelles (**Figure 4.18**) in eukaryotic cells that works together to modify, package, and transport lipids and proteins. It includes the nuclear envelope, lysosomes, and vesicles, which we've already mentioned, and the endoplasmic reticulum and Golgi apparatus, which we will cover shortly.

Although not technically *within* the cell, the plasma membrane is included in the endomembrane system because, as you will see, it interacts with the other endomembranous organelles. The endomembrane system does not include the membranes of either mitochondria or chloroplasts.

visual CONNECTION

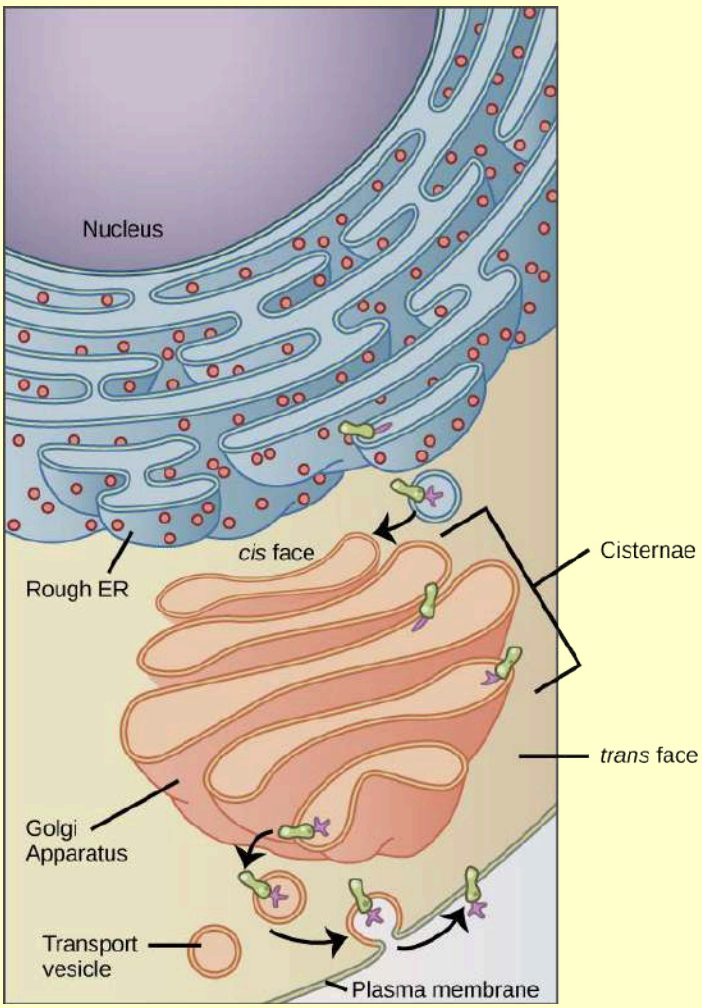


Figure 4.18 Membrane and secretory proteins are synthesized in the rough endoplasmic reticulum (RER). The RER also sometimes modifies proteins. In this illustration, a (green) integral membrane protein in the ER is modified by attachment of a (purple) carbohydrate. Vesicles with the integral protein bud from the ER and fuse with the cis face of the Golgi apparatus. As the protein passes along the Golgi's cisternae, it is further modified by the addition of more carbohydrates. After its synthesis is complete, it exits as an integral membrane protein of the vesicles that bud from the Golgi's **trans** face. When the vesicle fuses with the cell membrane, the protein becomes an integral portion of that cell membrane. (credit: modification of work by Magnus Manske)

If a peripheral membrane protein were synthesized inside the lumen of the ER, would it end up on the inside or outside of the plasma membrane?

a. The vesicle travels from the endoplasmic reticulum to get embedded in plasma membrane.
b. The vesicle travels from the Golgi to the plasma membrane to release the protein outside.
c. The vesicle travels from the endoplasmic reticulum to the plasma membrane, and returns to the Golgi apparatus to get modified.
d. The vesicle moves from the endoplasmic reticulum into the cytoplasmic area, remaining there.

The **endoplasmic reticulum (ER)** (Figure 4.18) is a series of interconnected membranous sacs and tubules that collectively modifies proteins and synthesizes lipids. However, these two functions are performed in separate areas of the ER: the rough ER and the smooth ER, respectively.

The hollow portion of the ER tubules is called the lumen or cisternal space. The membrane of the ER, which is a phospholipid bilayer embedded with proteins, is continuous with the nuclear envelope.

Rough ER

The **rough endoplasmic reticulum (RER)** is so named because the ribosomes attached to its cytoplasmic surface give it a studded appearance when viewed through an electron microscope (Figure 4.19).

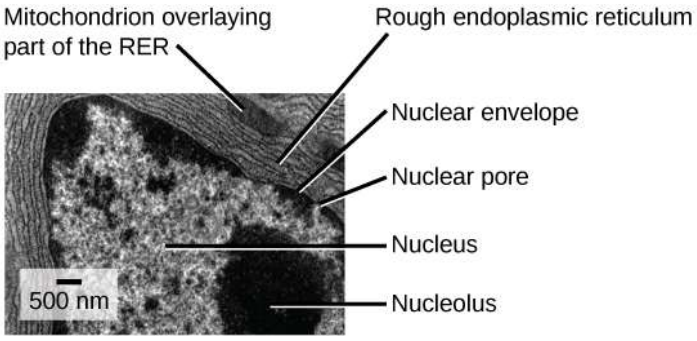


Figure 4.19 This transmission electron micrograph shows the rough endoplasmic reticulum and other organelles in a pancreatic cell. (credit: modification of work by Louisa Howard)

Ribosomes transfer their newly synthesized proteins into the lumen of the RER where they undergo structural modifications, such as folding or the acquisition of side chains. These modified proteins will be incorporated into cellular membranes—the membrane of the ER or those of other organelles—or secreted from the cell (such as protein hormones, enzymes). The RER also makes phospholipids for cellular membranes.

If the phospholipids or modified proteins are not destined to stay in the RER, they will reach their destinations via transport vesicles that bud from the RER's membrane (Figure 4.18).

Since the RER is engaged in modifying proteins (such as enzymes, for example) that will be secreted from the cell, you would be correct in assuming that the RER is abundant in cells that secrete proteins. This is the case with cells of the liver, for example.

Smooth ER

The **smooth endoplasmic reticulum (SER)** is continuous with the RER but has few or no ribosomes on its cytoplasmic surface (Figure 4.18). Functions of the SER include synthesis of carbohydrates, lipids, and steroid hormones; detoxification of medications and poisons; and storage of calcium ions.

In muscle cells, a specialized SER called the sarcoplasmic reticulum is responsible for storage of the calcium ions that are needed to trigger the coordinated contractions of the muscle cells.

You can watch an excellent animation of the endomembrane system **here (http://openstaxcollege.org/l/endomembrane)** .

How do the nucleus and the endomembrane system work together for protein synthesis?

a. The endomembrane system processes and ships proteins specified by the nucleus. In the nucleus, DNA is used to make RNA which exits the nucleus and enters the cytoplasm of the cell. The ribosomes on the rough ER use the RNA to create the different types of protein needed by the body.

b. The endomembrane system processes and ships proteins specified by the nucleus. From the nucleus, RNA exits and enters the cytoplasm of the cell. The ribosomes on the rough ER use the RNA to create the different types of protein needed by the body.

c. The endomembrane system processes and ships proteins specified by the nucleus. In the nucleus, DNA is used to make RNA which exits the nucleus and enters the cytoplasm of the cell. The smooth ER uses the RNA to create the different types of protein needed by the body.

d. The endomembrane system processes and ships proteins specified by the nucleus. In the nucleus, DNA is used to make RNA which exits the nucleus and enters the cytoplasm of the cell. The ribosomes on the smooth ER use the RNA to create the different types of protein needed by the body.

career CONNECTION

Cardiologist

Heart disease is the leading cause of death in the United States. This is primarily due to our sedentary lifestyle and our high trans-fat diets.

Heart failure is just one of many disabling heart conditions. Heart failure does not mean that the heart has stopped working. Rather, it means that the heart can't pump with sufficient force to transport oxygenated blood to all the vital organs. Left untreated, heart failure can lead to kidney failure and failure of other organs.

The wall of the heart is composed of cardiac muscle tissue. Heart failure occurs when the endoplasmic reticula of cardiac muscle cells do not function properly. As a result, an insufficient number of calcium ions are available to trigger a sufficient contractile force.

Cardiologists (cardi- = "heart"; -ologist = "one who studies") are doctors who specialize in treating heart diseases, including heart failure. Cardiologists can make a diagnosis of heart failure via physical examination, results from an electrocardiogram (ECG, a test that measures the electrical activity of the heart), a chest X-ray to see whether the heart is enlarged, and other tests. If heart failure is diagnosed, the cardiologist will typically prescribe appropriate medications and recommend a reduction in table salt intake and a supervised exercise program.

The Golgi Apparatus

We have already mentioned that vesicles can bud from the ER and transport their contents elsewhere, but where do the vesicles go? Before reaching their final destination, the lipids or proteins within the transport vesicles still need to be sorted, packaged, and tagged so that they wind up in the right place. Sorting, tagging, packaging, and distribution of lipids and proteins takes place in the **Golgi apparatus** (also called the Golgi body), a series of flattened membranes (**Figure 4.20**).

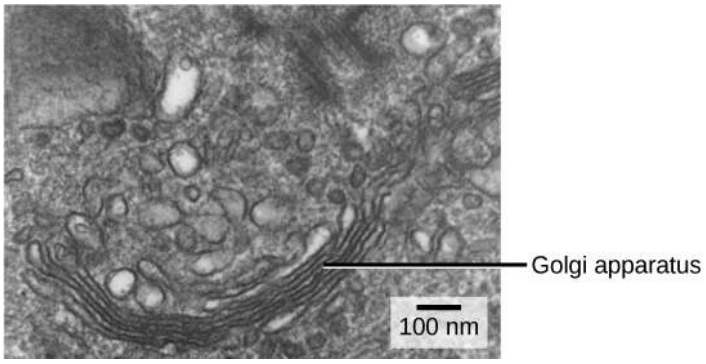


Figure 4.20 The Golgi apparatus in this white blood cell is visible as a stack of semicircular, flattened rings in the lower portion of the image. Several vesicles can be seen near the Golgi apparatus. (credit: modification of work by Louisa Howard)

The receiving side of the Golgi apparatus is called the *cis* face. The opposite side is called the *trans* face. The transport vesicles that formed from the ER travel to the *cis* face, fuse with it, and empty their contents into the lumen of the Golgi apparatus. As the proteins and lipids travel through the Golgi, they undergo further modifications that allow them to be sorted. The most frequent modification is the addition of short chains of sugar molecules. These newly modified proteins and lipids are then tagged with phosphate groups or other small molecules so that they can be routed to their proper destinations.

Finally, the modified and tagged proteins are packaged into secretory vesicles that bud from the *trans* face of the Golgi. While some of these vesicles deposit their contents into other parts of the cell where they will be used, other secretory vesicles fuse with the plasma membrane and release their contents outside the cell.

In another example of form following function, cells that engage in a great deal of secretory activity (such as cells of the salivary glands that secrete digestive enzymes or cells of the immune system that secrete antibodies) have an abundance of Golgi.

In plant cells, the Golgi apparatus has the additional role of synthesizing polysaccharides, some of which are incorporated into the cell wall and some of which are used in other parts of the cell.

career CONNECTION

Geneticist

Many diseases arise from genetic mutations that prevent the synthesis of critical proteins. One such disease is Lowe disease (also called oculocerebrorenal syndrome, because it affects the eyes, brain, and kidneys). In Lowe disease, there is a deficiency in an enzyme localized to the Golgi apparatus. Children with Lowe disease are born with cataracts, typically develop kidney disease after the first year of life, and may have impaired mental abilities.

Lowe disease is a genetic disease caused by a mutation on the X chromosome. The X chromosome is one of the two human sex chromosomes, as these chromosomes determine a person's sex. Females possess two X chromosomes while males possess one X and one Y chromosome. In females, the genes on only one of the two X chromosomes are expressed. Females who carry the Lowe disease gene on one of their X chromosomes are carriers and do not show symptoms of the disease. However, males only have one X chromosome and the genes on this chromosome are always expressed. Therefore, males will always have Lowe disease if their X chromosome carries the Lowe disease gene. The location of the mutated gene, as well as the locations of many other mutations that cause genetic diseases, has now been identified. Through prenatal testing, a woman can find out if the fetus she is carrying may be afflicted with one of several genetic diseases.

Geneticists analyze the results of prenatal genetic tests and may counsel pregnant women on available options. They may also conduct genetic research that leads to new drugs or foods, or perform DNA analyses that are used in forensic investigations.

Lysosomes

In addition to their role as the digestive component and organelle-recycling facility of animal cells, lysosomes are considered to be parts of the endomembrane system. Lysosomes also use their hydrolytic enzymes to destroy pathogens (disease-causing organisms) that might enter the cell. A good example of this occurs in a group of white blood cells called macrophages, which are part of your body's immune system. In a process known as phagocytosis or endocytosis, a section of the plasma membrane of the macrophage invaginates (folds in) and engulfs a pathogen. The invaginated section, with the pathogen inside, then pinches itself off from the plasma membrane and becomes a vesicle. The vesicle fuses with a lysosome. The lysosome's hydrolytic enzymes then destroy the pathogen (**Figure 4.21**).

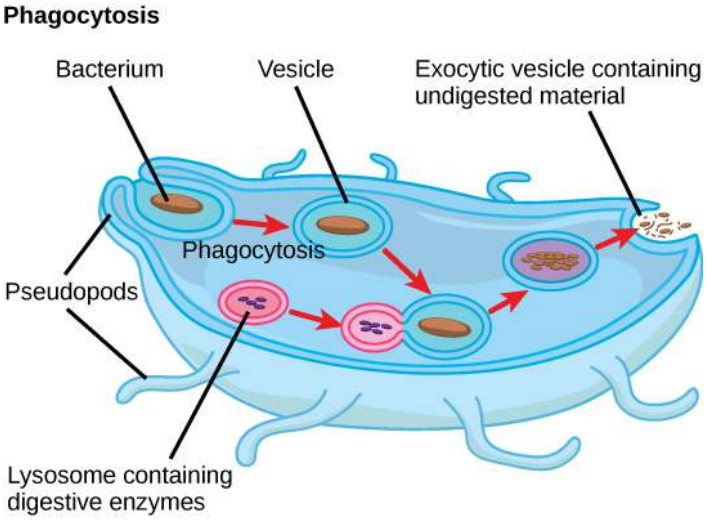


Figure 4.21 A macrophage has engulfed (phagocytized) a potentially pathogenic bacterium which then fuses with a lysosome within the cell to destroy the pathogen. Other organelles are present in the cell but for simplicity are not shown.

science practices CONNECTION for AP® Courses

Activity

Homemade Cell Project. Using inexpensive and common household items, create a model of a specific eukaryotic cell (e.g., neuron, white blood cell, plant root cell, or *Paramecium*) that demonstrates how at least three organelles work together to perform a specific function.

Think About It

A certain cell type functions primarily to synthesize proteins for export. What is the most likely route the newly made protein takes through the cell? Justify your prediction.

Section Summary

The endomembrane system includes the nuclear envelope, lysosomes, vesicles, the ER, and Golgi apparatus, as well as the plasma membrane. These cellular components work together to modify, package, tag, and transport proteins and lipids that form the membranes.

The RER modifies proteins and synthesizes phospholipids used in cell membranes. The SER synthesizes carbohydrates, lipids, and steroid hormones; engages in the detoxification of medications and poisons; and stores calcium ions. Sorting, tagging, packaging, and distribution of lipids and proteins take place in the Golgi apparatus. Lysosomes are created by the budding of the membranes of the RER and Golgi. Lysosomes digest macromolecules, recycle worn-out organelles, and destroy pathogens.

4.5 | Cytoskeleton

In this section, you will explore the following questions:

- How do the various components of the cytoskeleton perform their functions?

Connection for AP® Courses

All cells, from simple bacteria to complex eukaryotes, possess a cytoskeleton composed of different types of protein elements, including microfilaments, intermediate filaments, and microtubules. The cytoskeleton serves a variety of purposes: provides rigidity and shape to the cell, facilitates cellular movement, anchors the nucleus and other organelles in place, moves vesicles through the cell, and pulls replicated chromosomes to the poles of a dividing cell. These protein elements are also integral to the movement of centrioles, flagella, and cilia.

The information presented and the examples highlighted in the section support concepts and Learning Objectives outlined in Big Idea 1 of the AP Biology Curriculum Framework, as shown in the table below.

The Learning Objectives listed in the Curriculum Framework provide a transparent foundation for the AP® Biology course, an inquiry-based laboratory experience, instructional activities, and AP® exam questions. A Learning Objective merges required content with one or more of the seven Science Practices.

Big Idea 1	The process of evolution drives the diversity and unity of life.
Enduring Understanding 1.B	Organisms are linked by lines of descent from common ancestry
Essential Knowledge	**1.B.1** Organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.
Science Practice	**7.2** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.
Learning Objective	**1.15** The student is able to describe specific examples of conserved core biological processes and features shared by all domains or within one domain of life and how these shared, conserved core processes and features support the concept of common ancestry for all organisms.

Microfilaments

If you were to remove all the organelles from a cell, would the plasma membrane and the cytoplasm be the only components left? No. Within the cytoplasm, there would still be ions and organic molecules, plus a network of protein fibers that help maintain the shape of the cell, secure some organelles in specific positions, allow cytoplasm and vesicles to move within the cell, and enable cells within multicellular organisms to move. Collectively, this network of protein fibers is known as the **cytoskeleton**. There are three types of fibers within the cytoskeleton: microfilaments, intermediate filaments, and microtubules (**Figure 4.22**). Here, we will examine each.

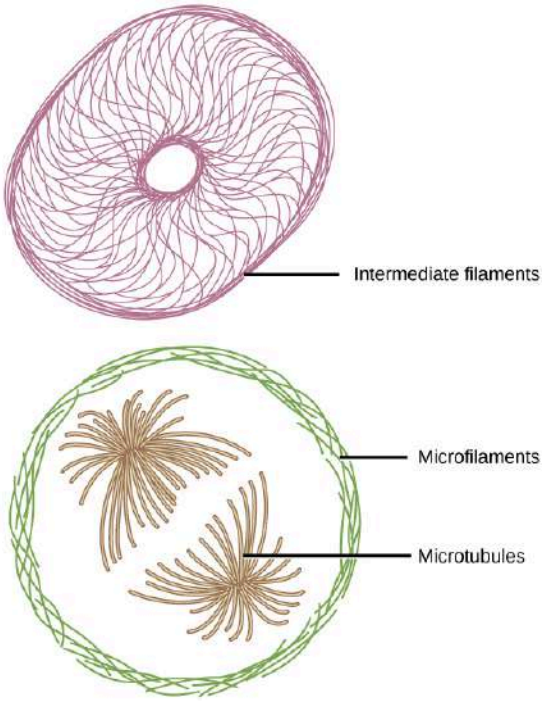


Figure 4.22 Microfilaments thicken the cortex around the inner edge of a cell; like rubber bands, they resist tension. Microtubules are found in the interior of the cell where they maintain cell shape by resisting compressive forces. Intermediate filaments are found throughout the cell and hold organelles in place.

Of the three types of protein fibers in the cytoskeleton, **microfilaments** are the narrowest. They function in cellular movement, have a diameter of about 7 nm, and are made of two intertwined strands of a globular protein called actin (**Figure 4.23**). For this reason, microfilaments are also known as actin filaments.

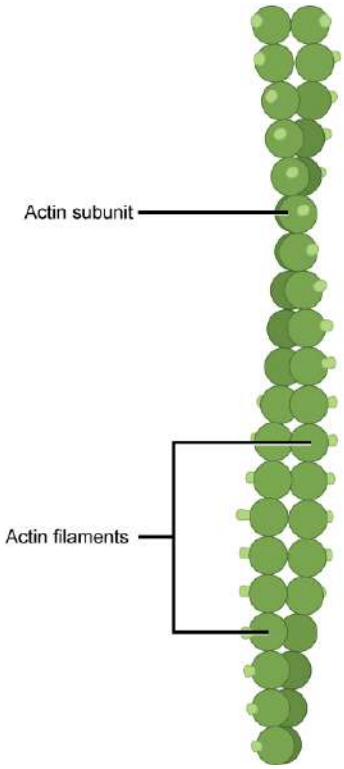


Figure 4.23 Microfilaments are made of two intertwined strands of actin.

Actin is powered by ATP to assemble its filamentous form, which serves as a track for the movement of a motor protein

called myosin. This enables actin to engage in cellular events requiring motion, such as cell division in eukaryotic cells and cytoplasmic streaming, which is the circular movement of the cell cytoplasm in plant cells. Actin and myosin are plentiful in muscle cells. When your actin and myosin filaments slide past each other, your muscles contract.

Microfilaments also provide some rigidity and shape to the cell. They can depolymerize (disassemble) and reform quickly, thus enabling a cell to change its shape and move. White blood cells (your body's infection-fighting cells) make good use of this ability. They can move to the site of an infection and phagocytize the pathogen.

LINK TO LEARNING

To see an example of a white blood cell in action, click **here (http://openstaxcollege.org/l/chasing_bcteria)** and watch a short time-lapse video of the cell capturing two bacteria. It engulfs one and then moves on to the other.

The Human Immunodeficiency Virus (HIV) infects and kills white blood cells. Over time, what affect does this have on the body's immune system?

a. The body's immune system would not be affected by this.

b. The body's immune system would not be able to fight off pathogens like bacteria with fewer white blood cells. This can increase the risk of illness in HIV patients.

c. The body's immune system, in order to recoup this loss, will produce more WBC's.

d. The body's immune system will fight the pathogens more vigorously in order to compensate for the fewer white blood cells.

Intermediate Filaments

Intermediate filaments are made of several strands of fibrous proteins that are wound together (**Figure 4.24**). These elements of the cytoskeleton get their name from the fact that their diameter, 8 to 10 nm, is between those of microfilaments and microtubules.

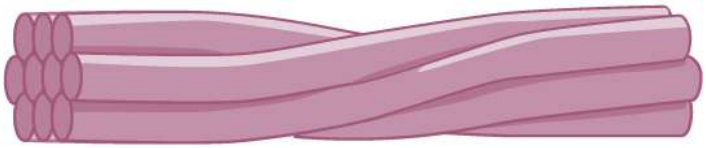


Figure 4.24 Intermediate filaments consist of several intertwined strands of fibrous proteins.

Intermediate filaments have no role in cell movement. Their function is purely structural. They bear tension, thus maintaining the shape of the cell, and anchor the nucleus and other organelles in place. **Figure 4.22** shows how intermediate filaments create a supportive scaffolding inside the cell.

The intermediate filaments are the most diverse group of cytoskeletal elements. Several types of fibrous proteins are found in the intermediate filaments. You are probably most familiar with keratin, the fibrous protein that strengthens your hair, nails, and the epidermis of the skin.

Microtubules

As their name implies, microtubules are small hollow tubes. The walls of the microtubule are made of polymerized dimers of α-tubulin and β-tubulin, two globular proteins (**Figure 4.25**). With a diameter of about 25 nm, **microtubules** are the widest components of the cytoskeleton. They help the cell resist compression, provide a track along which vesicles move through the cell, and pull replicated chromosomes to opposite ends of a dividing cell. Like microfilaments, microtubules can disassemble and reform quickly.

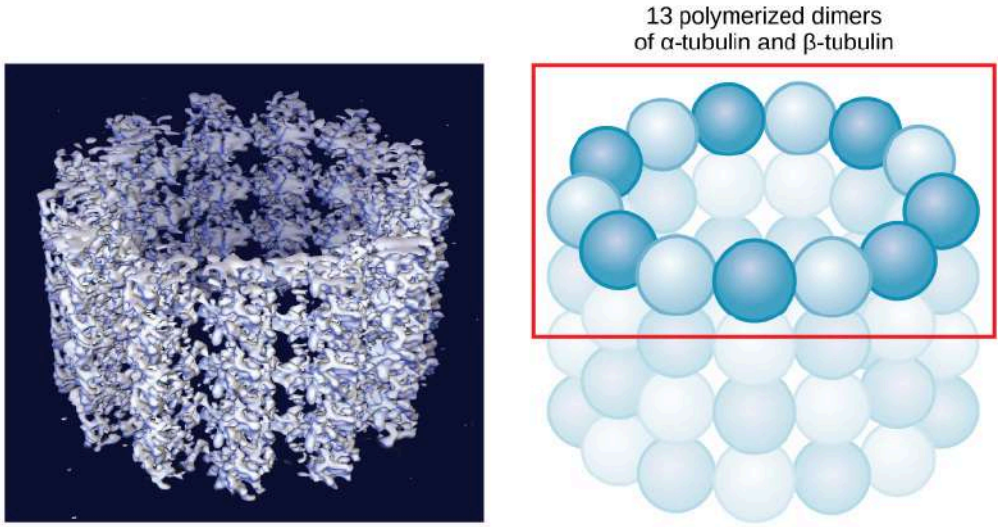


Figure 4.25 Microtubules are hollow. Their walls consist of 13 polymerized dimers of α-tubulin and β-tubulin (right image). The left image shows the molecular structure of the tube.

Microtubules are also the structural elements of flagella, cilia, and centrioles (the latter are the two perpendicular bodies of the centrosome). In fact, in animal cells, the centrosome is the microtubule-organizing center. In eukaryotic cells, flagella and cilia are quite different structurally from their counterparts in prokaryotes, as discussed below.

Flagella and Cilia

To refresh your memory, **flagella** (singular = flagellum) are long, hair-like structures that extend from the plasma membrane and are used to move an entire cell (for example, sperm, *Euglena*). When present, the cell has just one flagellum or a few flagella. When **cilia** (singular = cilium) are present, however, many of them extend along the entire surface of the plasma membrane. They are short, hair-like structures that are used to move entire cells (such as paramecia) or substances along the outer surface of the cell (for example, the cilia of cells lining the Fallopian tubes that move the ovum toward the uterus, or cilia lining the cells of the respiratory tract that trap particulate matter and move it toward your nostrils.)

Despite their differences in length and number, flagella and cilia share a common structural arrangement of microtubules called a "9 + 2 array." This is an appropriate name because a single flagellum or cilium is made of a ring of nine microtubule doublets, surrounding a single microtubule doublet in the center (**Figure 4.26**).

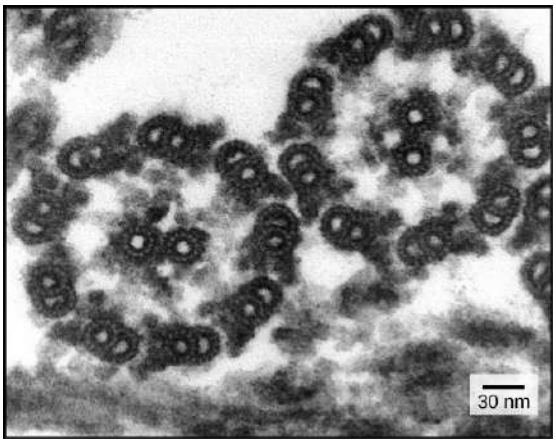


Figure 4.26 This transmission electron micrograph of two flagella shows the 9 + 2 array of microtubules: nine microtubule doublets surround a single microtubule doublet. (credit: modification of work by Dartmouth Electron Microscope Facility, Dartmouth College; scale-bar data from Matt Russell)

science practices CONNECTION for AP® Courses

Think About It

The ribosomes in bacterial cells and in human cells are made up of proteins and ribosomal RNA, suggesting that both kinds of cells share a common ancestor cell type. What are examples of other features of cells that provide evidence for common ancestry?

You have now completed a broad survey of the components of prokaryotic and eukaryotic cells. For a summary of cellular components in prokaryotic and eukaryotic cells, see **Table 4.1**.

Components of Prokaryotic and Eukaryotic Cells

Cell Component	Function	Present in Prokaryotes?	Present in Animal Cells?	Present in Plant Cells?
Plasma membrane	Separates cell from external environment; controls passage of organic molecules, ions, water, oxygen, and wastes into and out of cell	Yes	Yes	Yes
Cytoplasm	Provides turgor pressure to plant cells as fluid inside the central vacuole; site of many metabolic reactions; medium in which organelles are found	Yes	Yes	Yes
Nucleolus	Darkened area within the nucleus where ribosomal subunits are synthesized.	No	Yes	Yes
Nucleus	Cell organelle that houses DNA and directs synthesis of ribosomes and proteins	No	Yes	Yes
Ribosomes	Protein synthesis	Yes	Yes	Yes
Mitochondria	ATP production/cellular respiration	No	Yes	Yes
Peroxisomes	Oxidizes and thus breaks down fatty acids and amino acids, and detoxifies poisons	No	Yes	Yes
Vesicles and vacuoles	Storage and transport; digestive function in plant cells	No	Yes	Yes
Centrosome	Unspecified role in cell division in animal cells; source of microtubules in animal cells	No	Yes	No
Lysosomes	Digestion of macromolecules; recycling of worn-out organelles	No	Yes	No
Cell wall	Protection, structural support and maintenance of cell shape	Yes, primarily peptidoglycan	No	Yes, primarily cellulose
Chloroplasts	Photosynthesis	No	No	Yes
Endoplasmic reticulum	Modifies proteins and synthesizes lipids	No	Yes	Yes

Table 4.1

Components of Prokaryotic and Eukaryotic Cells

Cell Component	Function	Present in Prokaryotes?	Present in Animal Cells?	Present in Plant Cells?
Golgi apparatus	Modifies, sorts, tags, packages, and distributes lipids and proteins	No	Yes	Yes
Cytoskeleton	Maintains cell's shape, secures organelles in specific positions, allows cytoplasm and vesicles to move within cell, and enables unicellular organisms to move independently	Yes	Yes	Yes
Flagella	Cellular locomotion	Some	Some	No, except for some plant sperm cells.
Cilia	Cellular locomotion, movement of particles along extracellular surface of plasma membrane, and filtration	Some	Some	No

Table 4.1

Section Summary

The cytoskeleton has three different types of protein elements. From narrowest to widest, they are the microfilaments (actin filaments), intermediate filaments, and microtubules. Microfilaments are often associated with myosin. They provide rigidity and shape to the cell and facilitate cellular movements. Intermediate filaments bear tension and anchor the nucleus and other organelles in place. Microtubules help the cell resist compression, serve as tracks for motor proteins that move vesicles through the cell, and pull replicated chromosomes to opposite ends of a dividing cell. They are also the structural element of centrioles, flagella, and cilia.

4.6 | Connections between Cells and Cellular Activities

In this section, you will explore the following questions:

- What are the components of the extracellular matrix?
- What are the roles of tight junctions, gap junctions, and plasmodesmata in allowing cells to exchange materials with the environment and communicate with other cells?

Connection for AP® Courses

With the exception of gap junctions between animal cells and plasmodesmata between plant cells that facilitate the exchange of substances, the information presented in Section 4.6| Connections between Cells and Cellular Activities is not required for AP®. Concepts about cell communication and signaling processes that are required for AP®, including the features of cells that make communication possible, are covered in Chapter 9.

You already know that a group of similar cells working together is called a tissue. As you might expect that, if cells are to work together, they must communicate with one another, just as you need to communicate with others when you work on a group project. Let's take a look at how cells communicate with one another.

You already know that a group of similar cells working together is called a tissue. As you might expect, if cells are to work together, they must communicate with each other, just as you need to communicate with others if you work on a group project. Let's take a look at how cells communicate with each other.

The Science Practice Challenge Questions contain additional test questions for this section that will help you prepare for

the AP exam. These questions address the following standards:
[APLO 4.5][APLO 3.32][APLO 1.16][APLO 3.33][APLO 1.14][APLO 2.7][APLO 4.4]

Extracellular Matrix of Animal Cells

Most animal cells release materials into the extracellular space. The primary components of these materials are proteins, and the most abundant protein is collagen. Collagen fibers are interwoven with carbohydrate-containing protein molecules called proteoglycans. Collectively, these materials are called the **extracellular matrix** (Figure 4.27). Not only does the extracellular matrix hold the cells together to form a tissue, but it also allows the cells within the tissue to communicate with each other. How can this happen?

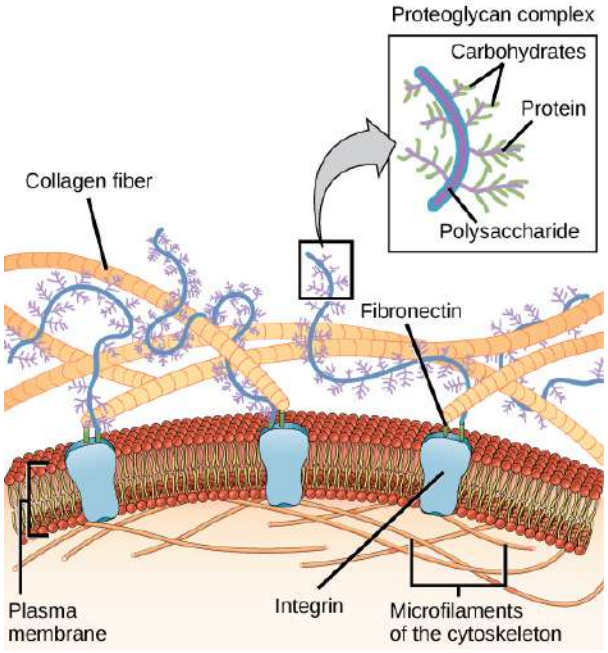


Figure 4.27 The extracellular matrix consists of a network of proteins and carbohydrates.

Cells have protein receptors on the extracellular surfaces of their plasma membranes. When a molecule within the matrix binds to the receptor, it changes the molecular structure of the receptor. The receptor, in turn, changes the conformation of the microfilaments positioned just inside the plasma membrane. These conformational changes induce chemical signals inside the cell that reach the nucleus and turn “on” or “off” the transcription of specific sections of DNA, which affects the production of associated proteins, thus changing the activities within the cell.

Blood clotting provides an example of the role of the extracellular matrix in cell communication. When the cells lining a blood vessel are damaged, they display a protein receptor called tissue factor. When tissue factor binds with another factor in the extracellular matrix, it causes platelets to adhere to the wall of the damaged blood vessel, stimulates the adjacent smooth muscle cells in the blood vessel to contract (thus constricting the blood vessel), and initiates a series of steps that stimulate the platelets to produce clotting factors.

Intercellular Junctions

Cells can also communicate with each other via direct contact, referred to as intercellular junctions. There are some differences in the ways that plant and animal cells do this. Plasmodesmata are junctions between plant cells, whereas animal cell contacts include tight junctions, gap junctions, and desmosomes.

Plasmodesmata

In general, long stretches of the plasma membranes of neighboring plant cells cannot touch one another because they are separated by the cell wall that surrounds each cell (Figure 4.8**b**). How then, can a plant transfer water and other soil nutrients from its roots, through its stems, and to its leaves? Such transport uses the vascular tissues (xylem and phloem) primarily. There also exist structural modifications called **plasmodesmata** (singular = plasmodesma), numerous channels that pass between cell walls of adjacent plant cells, connect their cytoplasm, and enable materials to be transported from cell to cell, and thus throughout the plant (Figure 4.28).

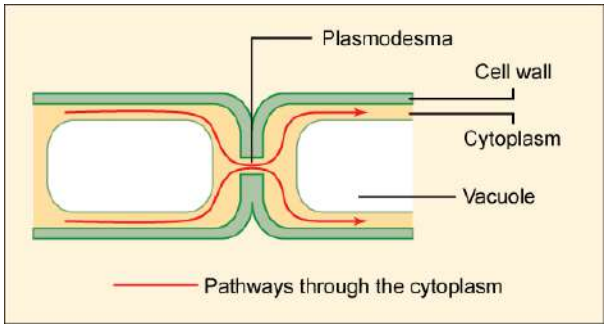


Figure 4.28 A plasmodesma is a channel between the cell walls of two adjacent plant cells. Plasmodesmata allow materials to pass from the cytoplasm of one plant cell to the cytoplasm of an adjacent cell.

Tight Junctions

A **tight junction** is a watertight seal between two adjacent animal cells (**Figure 4.29**). The cells are held tightly against each other by proteins (predominantly two proteins called claudins and occludins).

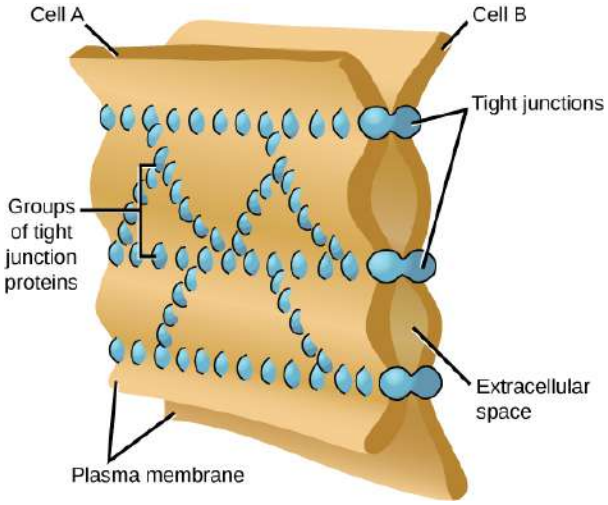


Figure 4.29 Tight junctions form watertight connections between adjacent animal cells. Proteins create tight junction adherence. (credit: modification of work by Mariana Ruiz Villareal)

This tight adherence prevents materials from leaking between the cells; tight junctions are typically found in epithelial tissues that line internal organs and cavities, and comprise most of the skin. For example, the tight junctions of the epithelial cells lining your urinary bladder prevent urine from leaking out into the extracellular space.

Desmosomes

Also found only in animal cells are **desmosomes**, which act like spot welds between adjacent epithelial cells (**Figure 4.30**). Short proteins called cadherins in the plasma membrane connect to intermediate filaments to create desmosomes. The cadherins join two adjacent cells together and maintain the cells in a sheet-like formation in organs and tissues that stretch, like the skin, heart, and muscles.

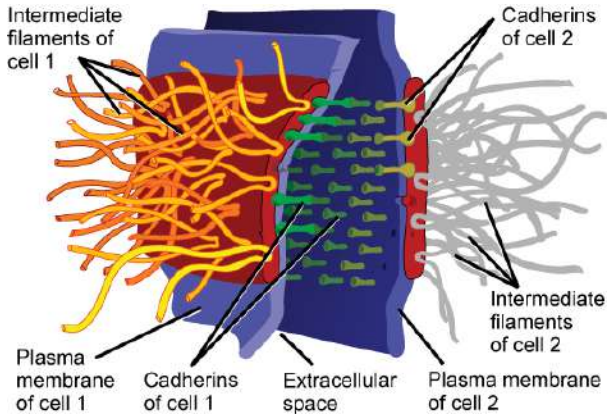


Figure 4.30 A desmosome forms a very strong spot weld between cells. It is created by the linkage of cadherins and intermediate filaments. (credit: modification of work by Mariana Ruiz Villareal)

Gap Junctions

Gap junctions in animal cells are like plasmodesmata in plant cells in that they are channels between adjacent cells that allow for the transport of ions, nutrients, and other substances that enable cells to communicate (**Figure 4.31**). Structurally, however, gap junctions and plasmodesmata differ.

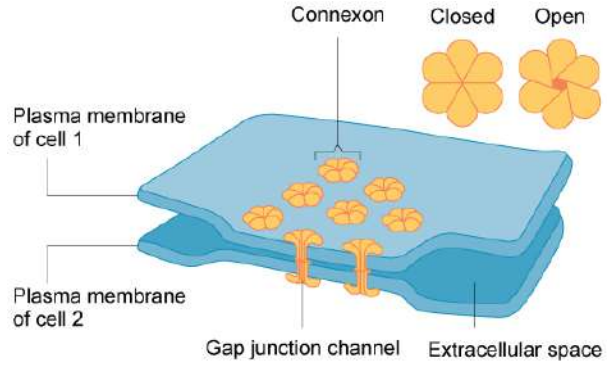


Figure 4.31 A gap junction is a protein-lined pore that allows water and small molecules to pass between adjacent animal cells. (credit: modification of work by Mariana Ruiz Villareal)

Gap junctions develop when a set of six proteins (called connexins) in the plasma membrane arrange themselves in an elongated donut-like configuration called a connexon. When the pores (“doughnut holes”) of connexons in adjacent animal cells align, a channel between the two cells forms. Gap junctions are particularly important in cardiac muscle: The electrical signal for the muscle to contract is passed efficiently through gap junctions, allowing the heart muscle cells to contract in tandem.

To conduct a virtual microscopy lab and review the parts of a cell, work through the steps of this **interactive assignment (http://openstaxcollege.org/l/microscopy_lab)** .

What are two similarities and two differences between plant and animal cells that can be seen under a microscope?

a. Plant cells have cell walls which provide structure to the plant and also chloroplasts which allow for photosynthesis. Animal cells do not have either of these structures. Both cells have nuclei, the command center of the cell, and cytoplasm, the gel-like solution that fills the cell.

b. Plant cells and animal cells have cell walls as well as nuclei. Plant cells have chloroplasts as well as plasmodesmata which are lacking in animal cells.

c. Plant cells have cell walls which provide structure to the plant and also chloroplasts which allow for photosynthesis. Animal cells do not have either of these structures. Animal cells and plant cells both have glyoxysomes as well cytoplasm.

d. Plant cells and animal cells both have a rigid plasma membrane as well as cytoplasm which is the gel-like solution that fills the cell. Plant cells have cell walls which provide structure to the plant and also chloroplasts which allow for photosynthesis. Animal cells do not have either of these structures.

KEY TERMS

cell theory see unified cell theory

cell wall rigid cell covering made of various molecules that protects the cell, provides structural support, and gives shape to the cell

central vacuole large plant cell organelle that regulates the cell's storage compartment, holds water, and plays a significant role in cell growth as the site of macromolecule degradation

centrosome region in animal cells made of two centrioles

chlorophyll green pigment that captures the light energy that drives the light reactions of photosynthesis

chloroplast plant cell organelle that carries out photosynthesis

chromatin protein-DNA complex that serves as the building material of chromosomes

chromosome structure within the nucleus that is made up of chromatin that contains DNA, the hereditary material

cilium (plural = cilia) short, hair-like structure that extends from the plasma membrane in large numbers and is used to move an entire cell or move substances along the outer surface of the cell

cytoplasm entire region between the plasma membrane and the nuclear envelope, consisting of organelles suspended in the gel-like cytosol, the cytoskeleton, and various chemicals

cytoskeleton network of protein fibers that collectively maintain the shape of the cell, secure some organelles in specific positions, allow cytoplasm and vesicles to move within the cell, and enable unicellular organisms to move independently

cytosol gel-like material of the cytoplasm in which cell structures are suspended

desmosome linkage between adjacent epithelial cells that forms when cadherins in the plasma membrane attach to intermediate filaments

electron microscope an instrument that magnifies an object using a beam of electrons passed and bent through a lens system to visualize a specimen

endomembrane system group of organelles and membranes in eukaryotic cells that work together modifying, packaging, and transporting lipids and proteins

endoplasmic reticulum (ER) series of interconnected membranous structures within eukaryotic cells that collectively modify proteins and synthesize lipids

eukaryotic cell cell that has a membrane-bound nucleus and several other membrane-bound compartments or sacs

extracellular matrix material (primarily collagen, glycoproteins, and proteoglycans) secreted from animal cells that provides mechanical protection and anchoring for the cells in the tissue

flagellum (plural = flagella) long, hair-like structure that extends from the plasma membrane and is used to move the cell

gap junction channel between two adjacent animal cells that allows ions, nutrients, and low molecular weight substances to pass between cells, enabling the cells to communicate

Golgi apparatus eukaryotic organelle made up of a series of stacked membranes that sorts, tags, and packages lipids and proteins for distribution

intermediate filament cytoskeletal component, composed of several intertwined strands of fibrous protein, that bears tension, supports cell-cell junctions, and anchors cells to extracellular structures

light microscope an instrument that magnifies an object using a beam visible light passed and bent through a lens system to visualize a specimen

lysosome organelle in an animal cell that functions as the cell's digestive component; it breaks down proteins, polysaccharides, lipids, nucleic acids, and even worn-out organelles

microfilament narrowest element of the cytoskeleton system; it provides rigidity and shape to the cell and enables cellular movements

microscope an instrument that magnifies an object

microtubule widest element of the cytoskeleton system; it helps the cell resist compression, provides a track along which vesicles move through the cell, pulls replicated chromosomes to opposite ends of a dividing cell, and is the structural element of centrioles, flagella, and cilia

mitochondria (singular = mitochondrion) cellular organelles responsible for carrying out cellular respiration, resulting in the production of ATP, the cell's main energy-carrying molecule

nuclear envelope double-membrane structure that constitutes the outermost portion of the nucleus

nucleoid central part of a prokaryotic cell in which the chromosome is found

nucleolus darkly staining body within the nucleus that is responsible for assembling the subunits of the ribosomes

nucleoplasm semi-solid fluid inside the nucleus that contains the chromatin and nucleolus

nucleus cell organelle that houses the cell's DNA and directs the synthesis of ribosomes and proteins

organelle compartment or sac within a cell

peroxisome small, round organelle that contains hydrogen peroxide, oxidizes fatty acids and amino acids, and detoxifies many poisons

plasma membrane phospholipid bilayer with embedded (integral) or attached (peripheral) proteins, that separates the internal content of the cell from its surrounding environment

plasmodesma (plural = plasmodesmata) channel that passes between the cell walls of adjacent plant cells, connects their cytoplasm, and allows materials to be transported from cell to cell

prokaryote unicellular organism that lacks a nucleus or any other membrane-bound organelle

ribosome cellular structure that carries out protein synthesis

rough endoplasmic reticulum (RER) region of the endoplasmic reticulum that is studded with ribosomes and engages in protein modification and phospholipid synthesis

smooth endoplasmic reticulum (SER) region of the endoplasmic reticulum that has few or no ribosomes on its cytoplasmic surface and synthesizes carbohydrates, lipids, and steroid hormones; detoxifies certain chemicals (like pesticides, preservatives, medications, and environmental pollutants), and stores calcium ions

tight junction firm seal between two adjacent animal cells created by protein adherence

unified cell theory a biological concept that states that all organisms are composed of one or more cells; the cell is the basic unit of life; and new cells arise from existing cells

vacuole membrane-bound sac, somewhat larger than a vesicle, which functions in cellular storage and transport

vesicle small, membrane-bound sac that functions in cellular storage and transport; its membrane is capable of fusing with the plasma membrane and the membranes of the endoplasmic reticulum and Golgi apparatus

CHAPTER SUMMARY

4.1 Studying Cells

A cell is the smallest unit of life. Most cells are so tiny that they cannot be seen with the naked eye. Therefore, scientists use microscopes to study cells. Electron microscopes provide higher magnification, higher resolution, and more detail than

light microscopes. The unified cell theory states that all organisms are composed of one or more cells, the cell is the basic unit of life, and new cells arise from existing cells.

4.2 Prokaryotic Cells

Prokaryotes are single-celled organisms of the domains Bacteria and Archaea. All prokaryotes have plasma membranes, cytoplasm, ribosomes, and DNA that is not membrane-bound. Most have peptidoglycan cell walls and many have polysaccharide capsules. Prokaryotic cells range in diameter from 0.1 to 5.0 μm.

As a cell increases in size, its surface area-to-volume ratio decreases. If the cell grows too large, the plasma membrane will not have sufficient surface area to support the rate of diffusion required for the increased volume.

4.3 Eukaryotic Cells

Like a prokaryotic cell, a eukaryotic cell has a plasma membrane, cytoplasm, and ribosomes, but a eukaryotic cell is typically larger than a prokaryotic cell, has a true nucleus (meaning its DNA is surrounded by a membrane), and has other membrane-bound organelles that allow for compartmentalization of functions. The plasma membrane is a phospholipid bilayer embedded with proteins. The nucleus's nucleolus is the site of ribosome assembly. Ribosomes are either found in the cytoplasm or attached to the cytoplasmic side of the plasma membrane or endoplasmic reticulum. They perform protein synthesis. Mitochondria participate in cellular respiration; they are responsible for the majority of ATP produced in the cell. Peroxisomes hydrolyze fatty acids, amino acids, and some toxins. Vesicles and vacuoles are storage and transport compartments. In plant cells, vacuoles also help break down macromolecules.

Animal cells also have a centrosome and lysosomes. The centrosome has two bodies perpendicular to each other, the centrioles, and has an unknown purpose in cell division. Lysosomes are the digestive organelles of animal cells.

Plant cells and plant-like cells each have a cell wall, chloroplasts, and a central vacuole. The plant cell wall, whose primary component is cellulose, protects the cell, provides structural support, and gives shape to the cell. Photosynthesis takes place in chloroplasts. The central vacuole can expand without having to produce more cytoplasm.

4.4 The Endomembrane System and Proteins

The endomembrane system includes the nuclear envelope, lysosomes, vesicles, the ER, and Golgi apparatus, as well as the plasma membrane. These cellular components work together to modify, package, tag, and transport proteins and lipids that form the membranes.

The RER modifies proteins and synthesizes phospholipids used in cell membranes. The SER synthesizes carbohydrates, lipids, and steroid hormones; engages in the detoxification of medications and poisons; and stores calcium ions. Sorting, tagging, packaging, and distribution of lipids and proteins take place in the Golgi apparatus. Lysosomes are created by the budding of the membranes of the RER and Golgi. Lysosomes digest macromolecules, recycle worn-out organelles, and destroy pathogens.

4.5 Cytoskeleton

The cytoskeleton has three different types of protein elements. From narrowest to widest, they are the microfilaments (actin filaments), intermediate filaments, and microtubules. Microfilaments are often associated with myosin. They provide rigidity and shape to the cell and facilitate cellular movements. Intermediate filaments bear tension and anchor the nucleus and other organelles in place. Microtubules help the cell resist compression, serve as tracks for motor proteins that move vesicles through the cell, and pull replicated chromosomes to opposite ends of a dividing cell. They are also the structural element of centrioles, flagella, and cilia.

4.6 Connections between Cells and Cellular Activities

Animal cells communicate via their extracellular matrices and are connected to each other via tight junctions, desmosomes, and gap junctions. Plant cells are connected and communicate with each other via plasmodesmata.

When protein receptors on the surface of the plasma membrane of an animal cell bind to a substance in the extracellular matrix, a chain of reactions begins that changes activities taking place within the cell. Plasmodesmata are channels between adjacent plant cells, while gap junctions are channels between adjacent animal cells. However, their structures are quite different. A tight junction is a watertight seal between two adjacent cells, while a desmosome acts like a spot weld.

REVIEW QUESTIONS

1. When viewing a specimen through a light microscope, what is a method that scientists use to make it easier to see individual components of cells?

a. a beam of electrons
b. high temperatures
c. radioactive isotopes
d. special stains

2. What is the basic unit of life?

a. cell
b. organism
c. organ
d. tissue

3. Which of the following statements is part of the cell theory?

a. All living organisms are made of cells.
b. All cells contain DNA that they pass on to daughter cells.
c. All cells depend on their surroundings to provide energy.
d. All cells have a nucleus.

4. Which of the following could most effectively be visualized with a scanning electron microscope?

a. cells swimming in a drop of pond water.
b. details of structures inside cells
c. a three-dimensional view of the surface of a membrane
d. the movement of molecules inside the cell

5. Who was the first to clearly identify and name individual cells?

a. Anton van Leeuwenhoek.
b. Matthias Schleiden
c. Robert Hooke
d. Theodore Schwann

6. Which of the following observations contributed to the cell theory?

a. Animal and plant cells have nuclei and organelles.
b. Non-living material cannot give rise to living organisms.
c. Prokaryotic and eukaryotic cells are surrounded by a plasma membrane.
d. Viruses replicate.

7. In order to obtain some materials and remove waste, what process is used by prokaryotes?

a. cell division
b. diffusion
c. flagellar motion
d. ribosomes

8. When bacteria lack fimbriae, what are they less likely to do?

a. Adhere to cell surfaces
b. retain the ability to divide
c. swim through bodily fluids
d. synthesize proteins

9. What is a difference between prokaryotic and eukaryotic cells?

a. Both cells have a nucleus but prokaryotic cells lack cytoplasm.
b. Both cells have cytoplasm but prokaryotic cells lack a nucleus.
c. Both cells have DNA but prokaryotic cells lack a cell membrane.
d. Both cells have a cell membrane but prokaryotic cells lack DNA.

10. Eukaryotic cells contain complex organelles that carry out their chemical reactions. Prokaryotes lack many of these complex organelles, although they have a variety of unique structures of their own. However, most prokaryotic cells can exchange nutrients with the outside environment faster than most eukaryotic cells. Why is this so?

a. Most prokaryotic cells are smaller, and have a higher surface-to-volume ratio, than eukaryotic cells.
b. Most prokaryotic cells are larger, and have a higher surface-to-volume ratio than eukaryotic cells.
c. Most prokaryotic cells are smaller, and have a lower surface-to-volume ratio than eukaryotic cells.
d. Prokaryotic cells are larger and have a lower surface-to-volume ratio than eukaryotic cells.

11. Which of the following is surrounded by two phospholipid bilayers?

a. lysosomes
b. ribosomes
c. nucleolus
d. nucleus

12. Peroxisomes got their name because hydrogen peroxide is _____.

a. a cofactor for the organelles' enzymes
b. incorporated into their membranes
c. produced during their oxidation reactions
d. used in their detoxification reactions

13. In plant cells, the function of the lysosomes is carried out by what?

a. nuclei
b. peroxisomes
c. ribosomes
d. vacuole

14. Which of the following is found both in eukaryotic and prokaryotic cells?

a. mitochondrion
b. nucleus
c. ribosomes
d. centrosomes

15. Which of the following structures is not found in prokaryotic cells?

a. plasma membrane
b. chloroplast
c. nucleoid
d. ribosome

16. Where would you find DNA, the genetic material, in an animal cell?

a. in the centriole
b. only in the mitochondria
c. in the mitochondria and the nucleus

17. Which of the following is most likely to have the greatest concentration of smooth endoplasmic reticulum (SER)?

a. a cell that secretes enzymes
b. a cell that destroys pathogens
c. a cell that makes steroid hormones
d. a cell that engages in photosynthesis

18. Which of the following sequences correctly lists in order the steps involved in the incorporation of a protein within a cell membrane?

a. synthesis of the protein on the ribosome; modification in the Golgi apparatus; packaging in the endoplasmic reticulum; modification in the vesicle
b. synthesis of the protein on the lysosome; modification in the Golgi; packaging in the vesicle; distribution in the endoplasmic reticulum
c. synthesis of the protein on the ribosome; modification in the endoplasmic reticulum; tagging in the Golgi; distribution via the vesicle
d. synthesis of the protein on the lysosome; packaging in the vesicle; distribution via the Golgi; modification in the endoplasmic reticulum

19. Which of the following is not a component of the endomembrane system?

a. endoplasmic reticulum
b. Golgi apparatus
c. lysosome
d. mitochondrion

20. Which of the following have the ability to disassemble and reform quickly?

a. intermediate filaments and microtubules
b. microfilaments and intermediate filaments
c. microfilaments and microtubules
d. only intermediate filaments

21. Which of the following do not play a role in intracellular movement?

a. intermediate filaments and microtubules
b. microfilaments and intermediate filaments
c. microfilaments and microtubules
d. only intermediate filaments

22. Which components of the cytoskeleton are responsible for the contraction of muscles?

a. intermediate filaments
b. microfilaments
c. microtubules

23. What type of junctions prevent the movement of chemicals between two adjacent animal cells?

a. desmosomes
b. gap junctions
c. plasmodesmata
d. tight junctions

24. Gap junctions are formed by _____.

a. gaps in the cell wall of plants
b. protein complexes that form channels between cells
c. tight, rivet-like regions in the membranes of adjacent cells
d. a tight knitting of membranes

25. Some animal cells produce extensive extracellular matrix. You would expect their ribosomes to synthesize large amounts of which of the following proteins?

a. actin
b. collagen
c. myosin
d. tubulin

26. Which of the following molecules are typically found in the extracellular matrix?

a. nucleic acids such as DNA
b. peptidoglycans
c. cellulose
d. proteoglycans

CRITICAL THINKING QUESTIONS

27. Which element of the cell theory has practical applications in health care because it promotes the use of sterilization and disinfection?

a. All cells come from pre-existing cells.
b. All living organisms are composed of one or more cells.
c. A cell is the basic unit of life.
d. A nucleus and organelles are found in prokaryotic cells.

28. What are the advantages and disadvantages of light microscopes? What are the advantages and disadvantages of electron microscopes?

a. Advantage: In light microscopes, the light beam does not kill the cell. Electron microscopes are helpful in viewing intricate details of a specimen and have high resolution. Disadvantage: Light microscopes have low resolving power. Electron microscopes are costly and require killing the specimen.
b. Advantage: Light microscopes have high resolution. Electron microscopes are helpful in viewing surface details of a specimen. Disadvantage: Light microscopes kill the cell. Electron microscopes are costly and low resolution.
c. Advantage: Light microscopes have high resolution. Electron microscopes are helpful in viewing surface details of a specimen. Disadvantage: Light microscopes can be used only in the presence of light and are costly. Electron microscopes uses short wavelength of electrons and hence have lower magnification.
d. Advantage: Light microscopes have high magnification. Electron microscopes are helpful in viewing surface details of a specimen. Disadvantage: Light microscopes can be used only in the presence of light and have lower resolution. Electron microscopes can be used only for viewing ultra-thin specimens.

29. Mitochondria are observed in plant cells that contain chloroplasts. Why do you find mitochondria in photosynthetic tissue?

a. Mitochondria are not needed but are an evolutionary relic.
b. Mitochondria and chloroplasts work together to use light energy to make sugars.
c. Mitochondria participate in the Calvin cycle/ light independent reactions of photosynthesis.
d. Mitochondria are required to break down sugars and other materials for energy.

30. In what situation, or situations, would the use of a light microscope be ideal? Why?

a. A light microscope is used to view the details of the surface of a cell as it cannot be viewed in detail by the transmission microscope.

b. A light microscope allows visualization of small living cells, which have been stained and cannot be viewed by scanning electron microscope.

c. A standard light microscope is used to view living organisms with little contrast to distinguish them from the background, which would be harder to see with the electron microscope.

d. A light microscope reveals the internal structures of a cell, which cannot be viewed by transmission electron microscopy.

31. The major role of the cell wall in bacteria is protecting the cell against changes in osmotic pressure, pressure caused by different solute concentrations in the environment. Bacterial cells swell, but do not burst, in low solute concentrations. What happens to bacterial cells if a compound that interferes with the synthesis of the cell wall is added to an environment with low solute concentrations?

a. Bacterial cells will shrink due to the lack of cell wall material.

b. Bacterial cells will shrink in size.

c. Bacterial cells may burst due to the influx of water.

d. Bacterial cells remain normal; they have alternative pathways to synthesize cell walls.

32. We have discussed the upper limits of cell size; yet, there is a lower limit to cell size. What determines how small a cell can be?

a. The cell should be large enough to escape detection.

b. The cell should be able to accommodate all the structures and metabolic activities necessary to survival.

c. The size of the cell should be large enough to reproduce itself.

d. The cell should be large enough to adapt to the changing environmental conditions.

33. Which of these is a possible explanation for the presence of a rigid cell wall in plants?

a. Plants remain exposed to changes in temperature and thus require rigid cell walls to protect themselves.

b. Plants are subjected to osmotic pressure and a cell wall helps them against bursting or shrinking.

c. Plant cells have a rigid cell wall to protect themselves from grazing animals.

d. Plant cells have a rigid cell wall to prevent the influx of waste material.

34. Bacteria do not have organelles; yet, the same reactions that take place on the mitochondria inner membrane, the phosphorylation of ADP to ATP, and chloroplasts, photosynthesis, take place in bacteria. Where do these reactions take place?

a. These reactions take place in the nucleoid of the bacteria.

b. These reactions occur in the cytoplasm present in the bacteria.

c. These reactions occur on the plasma membrane of bacteria.

d. These reactions take place in the mesosomes.

35. What are the structural and functional similarities and differences between mitochondria and chloroplasts?

a. Similarities: double membrane, inter-membrane space, ATP production, contain DNA. Differences: mitochondria have inner folds called cristae, chloroplast contains accessory pigments in thylakoids, which form grana and a stroma.

b. Similarities: DNA, inter-membrane space, ATP production, and chlorophyll. Differences: mitochondria have a matrix and inner folds called cristae; chloroplast contains accessory pigments in thylakoids, which form grana and a stroma.

c. Similarities: double membrane and ATP production. Differences: mitochondria have inter-membrane space and inner folds called cristae; chloroplast contains accessory pigments in thylakoids, which form grana and a stroma.

d. Similarities: double membrane and ATP production. Differences: mitochondria have inter-membrane space, inner folds called cristae, ATP synthase for ATP synthesis, and DNA; chloroplast contains accessory pigments in thylakoids, which, form grana and a stroma.

36. Is the nuclear membrane part of the endomembrane system? Why or why not?

a. The nuclear membrane is not a part of the endomembrane system as the endoplasmic reticulum is a separate organelle of the cell.

b. The nuclear membrane is considered a part of the endomembrane system as it is continuous with the Golgi body.

c. The nuclear membrane is part of the endomembrane system as it is continuous with the rough endoplasmic reticulum.

d. The nuclear membrane is not considered a part of the endomembrane system as the nucleus is a separate organelle.

37. What happens to the proteins that are synthesized on free ribosomes in the cytoplasm? Do they go through the Golgi apparatus?

a. These proteins move through the Golgi apparatus and enter in the nucleus.

b. These proteins go through the Golgi apparatus and remain in the cytosol.

c. The proteins do not go through the Golgi apparatus and move into the nucleus for processing.

d. The proteins do not go through the Golgi apparatus and remain free in the cytosol.

38. What are the similarities and differences between the structures of centrioles and flagella?

a. Centrioles and flagella are made of microtubules but show different arrangements.

b. Centrioles are made of microtubules but flagella are made of microfilaments and both show the same arrangement.

c. Centrioles and flagella are made of microfilaments. Centrioles have a 9 + 2 arrangement.

d. Centrioles are made of microtubules and flagella are made of microfilaments and both have different structures.

39. Inhibitors of microtubule assembly, vinblastine for example, are used for cancer chemotherapy. How does an inhibitor of microtubule assembly affect cancerous cells?

a. The inhibitors restrict the separation of chromosomes, thereby stopping cell division.

b. The inhibition of microtubules interferes with the synthesis of proteins.

c. The inhibitors bind the microtubule to the nuclear membrane, stopping cell division.

d. The inhibitor interferes with energy production.

40. How do cilia and flagella differ?

a. Cilia are made of microfilaments and flagella of microtubules.

b. Cilia are helpful in the process of engulfing food. Flagella are involved in the movement of the organism.

c. Cilia are short and found in large numbers on the cell surface whereas flagella are long and fewer in number.

d. Cilia are found in prokaryotic cells and flagella in eukaryotic cells.

41. In which human tissues would you find desmosomes? Think of tissues that undergo strong mechanical stress and must be held together with some flexibility.

a. bone cells and cartilage cells

b. muscle cells and skin cells

c. nerve cells and muscle cells

d. secretory cells and muscle cells

42. If there is a mutation in the gene for collagen, such as the one involved in Ehlers-Danlos syndrome, and the individual produces defective collagen, how would it affect coagulation?

a. The syndrome affects the clotting factors and platelet aggregation.

b. The disease leads to hyper-coagulation of blood.

c. Coagulation is not affected because collagen is not required for coagulation.

d. The disease occurs due to the breakdown of platelets.

43. How does the structure of a plasmodesma differ from that of a gap junction?

a. Gap junctions are essential for transportation in animal cells and plasmodesmata are essential for the movement of substances in plant cells.

b. Gap junctions are found to provide attachment in animal cells and plasmodesmata are essential for attachment of plant cells.

c. Plasmodesmata are essential for communication between animal cells and gap junctions are necessary for attachment of cells in plant cells.

d. Plasmodesmata help in transportation and gap junctions help in attachment, in plant cells.

TEST PREP FOR AP® COURSES

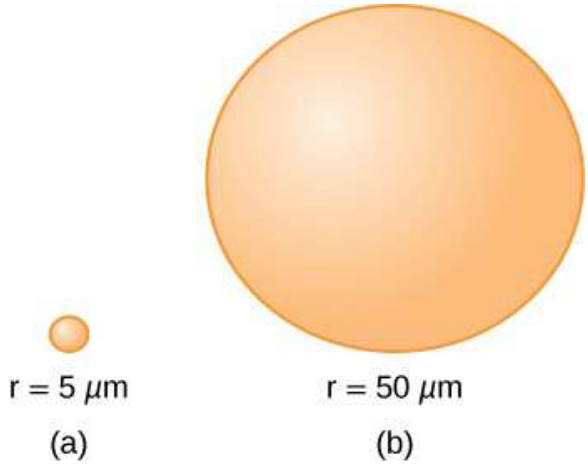
44. Which of the following organisms appear first in the fossil record?

a. archaea
b. fish
c. protists
d. plants

45. Why is it challenging to study bacterial fossils and determine if the fossils are members of the domain archaea, rather than bacteria?

a. Bacteria lack rigid structures, thus do not form fossils.
b. Bacteria have rigid structures, but their fossil impression is scarce.
c. Fossils of bacteria are rarely found because bacteria were not abundant in the past.
d. A fossil of bacteria changes overtime due to the presence of new bacteria living on them.

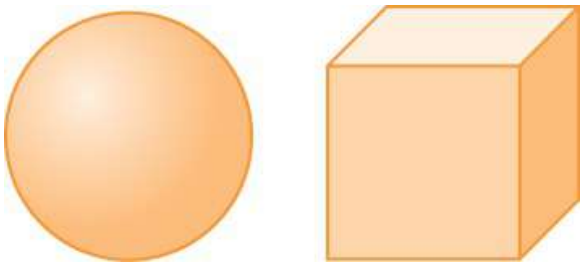
46.



Pictured are two cells along with their radius. What does cell B likely have when compared to cell A?

a. smaller surface area and larger volume
b. larger surface area and smaller volume
c. smaller surface area-to-volume ratio
d. larger surface area-to-volume ratio

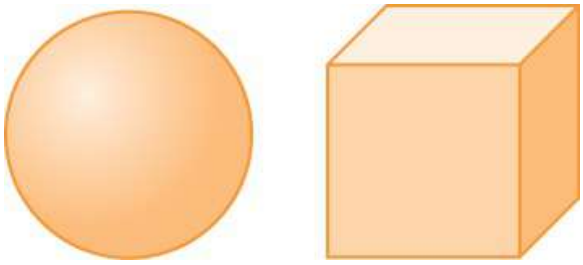
47.



Consider the shapes. The diameter of the sphere is equal to $1\ mm$ and the side of the cube is also equal to $1\ mm$. What is the ratio of the surface to volume ratios for the sphere and the cube?

a. 3 : 1
b. 4 : 1
c. 1 : 1
d. 2 : 1

48.



Which of the following is true regarding the surface-to-volume ratios of the cube and the sphere?

a. The sphere will have a higher surface area than the cube.
b. The sphere will have a higher volume than the cube.
c. The sphere will have a higher surface area-to-volume ratio than the cube.
d. Their surface area-to-volume ratios will be equal.
e. The sphere will have a lower surface area-to-volume ratio than the cube.

49. What is the major consideration in setting the lower limit of cell size?

a. The cell must be large enough to fight the pathogens
b. The cell must be large enough to attach to a substrate.
c. The lower limit should be small enough, for the cell to move in the fluid efficiently.
d. The cell size must be small as to fit all the processes and structures to support life.

50. Which of the following structures has the same general structure in Archaea, Bacteria, and Eukarya, pointing to a common origin?

a. centriole
b. cytoplasmic membrane
c. Golgi apparatus
d. nucleus

51. Why does the structure of the cytoplasmic membrane point to a common ancestor?

a. The presence of a cytoplasmic membrane in every organism does not point to a common ancestry.

b. The similar arrangement of phospholipids and proteins points to common ancestry.

c. The lipid nature of the membrane makes it the most primitive trait.

d. The similar effect of temperature on the membrane makes it the ancestral trait.

52. Which organelles would be present in high numbers in the leg muscles of a marathon runner?

a. centrioles

b. chloroplasts

c. mitochondria

d. peroxisome

53. Macrophages ingest and digest many pathogens. Which organelle plays a major role in the activity of macrophages?

a. chloroplast

b. lysosome

c. nucleus

d. peroxisome

54. You are looking at a sample under a light microscope and observe a new type of cell. You come to the conclusion that it is a bacterium and not a eukaryotic cell. What would you observe to come to this conclusion?

a. the cell has a cell wall

b. the cell has a flagellum

c. the cell does not have a nucleus

55. Thiomargarita namibiensis is a large single cell organism, which can reach lengths of $700\,\mu m$. The cell is classified as a bacterium. What is the main argument to justify the classification?

a. This organism shows simple diffusion for the uptake of nutrients and is thus classified as a bacterium.

b. This organism does not show presence of any cell organelles, and thus is classified as a bacterium.

c. the existence of these organisms in long chains and pearl appearance

d. The organism demonstrates characteristics of gram-negative bacteria, and thus is classified as a bacterium.

56. Radioactive amino acids are fed to a cell in culture for a short amount of time. This is called a pulse. You follow the appearance of radioactive proteins in the cell compartments. In which organelles and in what order does radioactivity appear?

a. endoplasmic reticulum - lysosomes - Golgi body - vesicle - extracellular region

b. endoplasmic reticulum - vesicles - Golgi body - vesicles - extracellular region

c. Golgi Body - vesicles - endoplasmic reticulum - vesicles - extracellular region

d. nucleus - endoplasmic reticulum - Golgi body - vesicle - extracellular region

57. With which cellular structure does the extracellular matrix interact?

a. cytoskeleton

b. nucleus

c. smooth endoplasmic reticulum

58. Which structure or structures allow bacteria to move about?

a. fimbriae only

b. flagella only

c. flagella and fimbriae

d. plasmid and capsule

59. Cells lining the intestine absorb a lot of nutrients. How did those cells adapt to their function?

a. Cells use cilia to move nutrients to their surface.

b. Cells grow much larger than adjacent cells to increase intake

c. Cells are flat and thin to absorb more nutrients.

d. Membrane folds called microvilli increase the surface area.

SCIENCE PRACTICE CHALLENGE QUESTIONS

60. Describe structural and functional similarities between mitochondria and chloroplasts that provide evidence of common ancestry.

61. Explain how the structural and functional differences between mitochondria and chloroplasts provide evidence of adaptations among common ancestral organisms.

62. Examine the differences and similarities in the structural features of animal and plant cells. **Justify the claim** that both animals and plants have common ancestors based on your observations.

63. What conserved core processes are common to both animals and plants? **Construct an explanation** of the differences based on the selective advantages provided in different environments.

64. Louis Sullivan described architectural design as "form follows function." For example, a window is designed to add light to a space without heat transport. A door is designed to allow access to a space. Windows and doors have different functions and so take different forms. Biological systems are not designed, but selected from random trials by interaction with the environment. Apply Sullivan's principle to **explain** the relationship of function and form for each pair of cellular structures below.

a. Plasma membrane and endoplasmic reticulum
b. Mitochondrion and chloroplast
c. Rough endoplasmic reticulum and smooth endoplasmic reticulum
d. Flagella and cilia
e. Muscle cells and secretory cells

65. Complex multicellular organisms share nutrients and resources, and their cells communicate with each other. A society may encourage cooperation among individuals while discouraging selfish behavior to increase the overall success of the social system, sometimes at the expense of the individual. Scientific questions are testable and often attempt to reveal a mechanism responsible for a phenomenon. **Pose** three **questions** that can be used to examine the ways in which a social system regulates itself. Be prepared to share these in small group discussions with your classmates about the similarities between these regulatory strategies and the analogous roles of plasmodesmata and gap junctions in cell communication.

66. Plasmodesmata in vascular plants and gap junctions in animals are examples of specialized features of cells. Mechanisms by which transport occurs between cells evolved independently within several eukaryotic clades. **Explain**, in terms of cellular cooperation, the selective advantages provided by such structures.

67. Mammalian red blood cells have no nuclei, must originate in other tissue systems, are relatively long-lived, are small with shapes that actively respond to their environment, and are metabolic anaerobes. Other vertebrates have red blood cells that are usually nucleated and are often relatively large, aerobic, self-replicating, and short-lived.

To connect these facts to biology, questions need to be asked. The questions that you pose will depend on the path your class is taking through the curriculum. Begin by summarizing what you know:

- What are the functions of a eukaryotic cell nucleus?
- What is the approximate average size of a human red blood cell?
- What is the range of blood vessel diameters in adult humans?
- What is the range of red blood cell size in vertebrates?
- What is the average lifetime of a human red blood cell?
- How can you show how cell production is stimulated using examples from particular systems?
- How is cell death controlled?
- What biochemical cycles are associated with anaerobic and aerobic respiration, and what are the important differences between these?
- What process is involved in the transport of oxygen and carbon dioxide into and out of red blood cells?
- What behaviors and dynamic homeostatic processes might be associated with the properties of red blood cells in mammalian and nonmammalian organisms?
- What do you know about the evolutionary divergences among vertebrates?

Your summary has revealed some similarities and differences among vertebrate erythrocyte and circulatory system structures. Scientific questions are testable. They can be addressed by making observations and measurements and analyzing the resulting data.

A. **Pose** three scientific **questions** that arise from your summaries of what you know about erythrocytes and capillary size.
B. For each question you pose, **predict** what you believe would be the answer and **provide reasoning** for your prediction.
C. **Describe** an approach you think can be used to obtain data to test your prediction.
D. In the production of mammalian red blood cells, erythrocytes that have not yet matured and are still synthesizing heme proteins are surrounded by a macrophage. Predict the role of the macrophage in the maturation of a red blood cell.

68. Mitochondria have DNA that encode proteins related to the structures and functions of the organelles. The replication appears to occur continuously, however, many questions about control of replication rate and segregation during mitosis are yet unanswered. Many diseases are caused by mitochondrial dysfunction. Mitophagy, as the name suggests, leads to the destruction of mitochondria. **Predict** whether or not cellular control mechanisms involving the regulation of mitochondrial DNA by the nucleus exist. Make use of what you know about selection and homeostasis as they apply to both the organism and to the organelle.