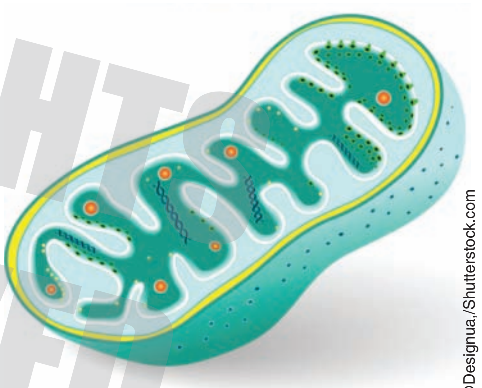
3

The Cell As a City

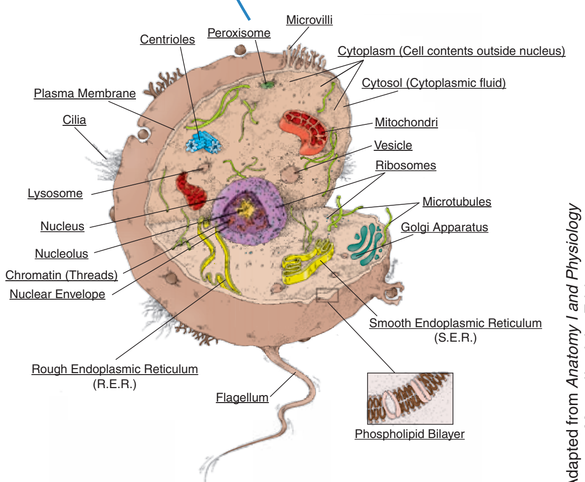
ESSENTIALS

Theta and Joules are in a clique – Sally is not accepted

The cell is like a city

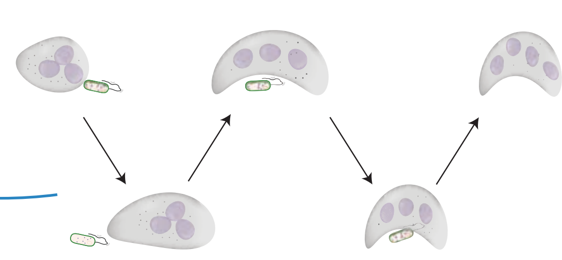


Mitochondria



A cell with its organelles

Adapted from *Anatomy I and Physiology Lecture Manual* by John Erickson



Primitive cells absorb mitochondria-like organisms

CHECK IN

From reading this chapter, you will be able to:

- Explain how differences caused by inherited organelles could have societal implications.
- Describe how the characteristics that are valued change from culture to culture and over time.
- Outline the cell theory, list and describe types of cells, and explain endosymbiosis.
- List and describe the organelles found in a cell, and explain their main functions.
- Explain the processes of diffusion, osmosis, facilitated diffusion, active transport, and bulk transport.

The Case of the Meddling Houseguest: A Friendship Divided

Theta and Joules liked their friend Sally, but when they entered college, they learned that Sally was different. When they were all young, they played together on the block, went to each other's birthday parties, and had some great sleepovers. "We had a lot of fun with Sally in sixth grade . . . I wish she could join our sorority," said Theta. Aghast at the thought, Joules replied, "Don't even say it – you know what that would mean for us. We shouldn't even admit that we know her."

"Why can I not hang out with people I like? . . . Am I not allowed to be Sally's friend because of some test?" thought Theta. "There is no law against me being friends with Sally!" exclaimed Theta, after a long pause. Joules dismissed Theta smugly, "You know you can't do it. It will never happen." They were expecting Sally to come into the dorm any minute. Sally was expecting to hang out with them as usual. But on this day, their friendship had to end. On this day, Joules and Theta were going to pledge their new sorority . . . and Sally did not have the mark.

It was an advanced society, in 2113 with all of the comforts – space travel beyond the solar system, teleporting, and no more diseases that the ancients had; instead there were life spans approaching two centuries for the marked people. Humans had it better than ever, and teens had the world in their hands. Everyone with parents that had any sense had a mark on their children to denote their superior genetic lineage. People in the line of descent from genetically modified mitochondria had an "M" on the inside of their ears. Their life expectancy was much higher and their health much better than those without the mark. Finding out about one's mitochondrial DNA was easy, with tests dating back over 100 years to trace the origin of one's genes.

Mitochondria

Is the organelle that makes energy for a cell.

Organelle (subcellular structure)

Structures that function within cells in a discrete manner

Mitochondria are organelles that make energy for a cell; they are inherited from mother to children because they have their own genetic material and divide on their own. Mitochondria are, in fact, separate structures existing within our cells. They were absorbed some 2.5 billion years ago, with their own set of DNA, making them houseguests in our bodies.

The genes in the mitochondria stay intact from generation to generation. "This is why the mark was so important – the health benefits," thought Theta. Mitochondrial DNA with modified genes of a particular line of mitochondria made people much healthier, free of many diseases in the society of this story. Mitochondria are the meddling houseguests in the title because defects in them cause a range of diseases. For example,

CHECK UP SECTION

The exclusion of people in our futuristic science fiction story reflects a theme in human society and history. As a result of cell differences between Theta and Sally, their friendship ended – each possessed a different type of mitochondrion.

Choose a particular situation in which a social stratification (layering) system is set up in a society, in which one group thinks it is better than another. You may choose a present system or one of the past. Is the stratification system reasonable? Is the system based on cell biology? What are the system's benefits? What are its drawbacks?

mitochondrial defects in the 21st century were responsible for many ailments, ranging from heart disease and diabetes to chronic sweating, optic nerve disorders, and epilepsy.

Joules told Theta, "People without the mark are jealous of us because they die earlier and have a worse life with more diseases. You know Sally would never understand us. Sally's genes are still from the 21st century." But something still bothered Theta: *She liked Sally*. Sally came into the dorm and Joules explained that they were leaving for the sorority. Sally knew what that meant and said good-bye. Theta looked deeply at Sally, realizing that their past was gone and that they would not see each other again as friends. Sally and Theta both had a single tear in their eyes and they knew they were part of each other's youth . . . and that meant something.

But Theta looked back one last time and said thoughtfully to herself, "She's not one of us."

Culture, Biology, and Social Stratification

Culture plays an important role in defining what is desirable and valued in society. Often decisions on what it means to be "better" are based on cell biology. Our genetic material makes each of us unique and guides the workings of our cells. We all have the same set of cell structures or organelles, but, as in our story, genetic variations give each person unique characteristics. While the opening story is science fiction, its possibilities are real. Gene technology is improving human health and has the potential to "design" human genes and organelles, possibly leading to social issues like those described in the conflict faced by Sally, Joules, and Theta.

Biological differences may lead to social changes based on what a society values at any one time. For example, research shows that certain biological features are used to decide social value of people: symmetry of one's face, body fat distribution in both genders, and musculature in males; smooth skin, good teeth, and a uniform gait. These are all biologically determined, based on how our cell structures work together. Much as mitochondrial inheritance, described in the story dictates health and organismal functioning, all cell structures give living systems their characteristics.

Historically, all cultures have used biology to classify people. Humans are susceptible to group messages, such as the one that influenced Theta's and Joules' final decision to abandon their friendship with Sally. The average American is exposed to about 3,000 marketing messages per day. This sets up a value system that requires us to reflect on how biology and society can affect our thinking.

BODY ART AND SKIN BIOLOGY IN SOCIETY

Body alterations in the quest for physical beauty are as old as history. Egyptians used cosmetics in their First Dynasty (3100–2907 BC). Hairstyles, corsets, body-weight goals, and body piercing and tattooing trends have changed through human history. Scars have been viewed as masculine and a mark of courage, and tattoos were drawn and carved in ancient European, Egyptian, and Japanese worlds.

Body art was popular in modern western society among the upper classes in the early 19th century. It lost favor due to stories of disease spreading because of unsanitary tattoo practices. Only the lower classes adopted body art to show group affiliation. Tattooing has recently gained popularity; but body art has been used as a symbol of self-expression and as a social-stratification mechanism in many cultures: Indian tattoos mark caste; Polynesians used marks for showing marital status; the Nazis marked groups from their elite SS to concentration camp prisoners; and U.S. gangs use it to show group membership. Tattooing has been firmly established in societies and continues to grow in popularity in the United States.

The canvas for tattoos is skin, which is part of the integumentary system and has a variety of functions in humans (Figure 3.1). It

- maintains temperature;
- stores blood and fat; and
- provides a protective layer.

We will discuss this important system in a later chapter.

Figure 3.1 Tattoos and body art. Dyes penetrate into the skin cells of a tattoo.

In this chapter, we will look at the structure and function of the eukaryotic cell. We will see that, while there are marked differences between plant and animal cells, the basic processes carried out at the cellular level are remarkably the same, as are those of simple, unicellular organisms. We will compare the organelles (structures) of the cell to functions of a city to emphasize that all parts are needed. Each organelle has its own duties, and the parts work together to make an efficient machine. We begin by looking at the development of the microscope, without which our understanding of cells and how they function would be incomplete.

Exploring the Cell

The Microscope

The human body is composed of over 10 trillion cells, and there are over 200 different types of cells in a typical animal body, with an amazing variety in sizes (see Figure 3.2). Despite the variety in size, all of these cells and the structures within them are too small

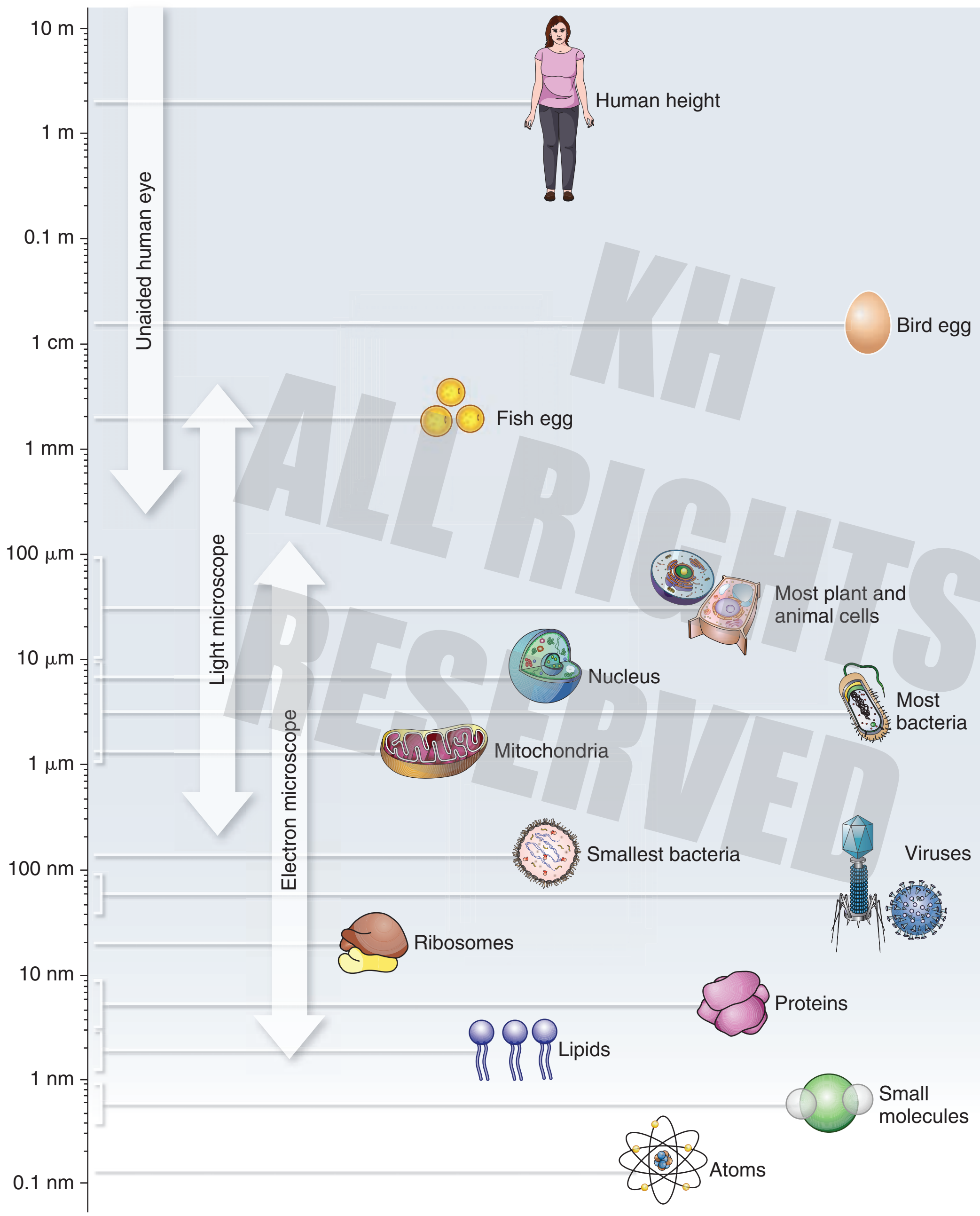


Figure 3.2 Biological size and cell diversity. When comparing the relatives' sizes of cells, we use multiples of 10 to show differences. The largest human cell, the female egg, is 100 µm, while the smallest bacterial cell is 1000 times smaller at 100 nm. Most cells are able to be seen with the light microscope. The smallest object a human eye can see is about 1 mm, the size of a human egg cell (or a grain of sand). From *Introductory Plant Science*, by Cynthia McKenney et al.

to be visible to our naked eyes and can only be identified by using microscopes to magnify them.

Compound light microscope

Microscope that uses two sets of lenses (an ocular and an objective lens).

Magnification

Is the amount by which an image size is larger than the object's size.

There are several types of microscopes; perhaps the one with which you are already familiar is the compound light microscope. The compound light microscope uses two lenses: an ocular and an objective lens. Each of these is a convex lens, meaning that its center is thicker than its ends. Convex lenses bring light to a central, converging point to magnify the specimen. A microscope's parts are seen in Figure 3.3.

The purpose of a microscope is to magnify subcellular parts. What is magnification? Magnification is the amount by which an image size is larger than the object's size. If a hair cell's image is 10 times bigger than its original object, the magnification is 10 times. If it is 100 times bigger, then the magnification is 100 times. The microscope uses two lenses to magnify the specimen: an ocular (eyepiece), which generally magnifies between 10 and 20 times, and a series of objective lenses (each with higher magnifications). The total magnification of a specimen is equal to the ocular (in this example let's use10 times) times the magnification of one of the objective lenses.

Most animal cells are only 10–30 µm in width. It would take over 20 cells to span the width of a single millimeter. Recall that a millimeter is only as wide as the wire used to make a paper clip. See Table 3.1 for measurements used for looking at living structures.

How were cells and their smaller components discovered using the microscope? Anton van Leeuwenhoek and Marcello Malpighi built microscopes in the late 1600s. At this time, those instruments were very rudimentary. They consisted of a lens or a combination of lenses to magnify smaller objects, including cells. Both scientists used their instruments to observe blood, plants, single-celled animals, and even sperm. Van Leeuwenhoek's microscope is shown in Figure 3.4. At about the same time that van Leeuwenhoek and Malpighi were making their observations, Robert Hooke (1635–1703) coined the term *cell*, as he peered through a primitive microscope of his own construction. When he viewed tissues of a cork plant, Hooke saw what seemed to be small cavities separated by walls, similar to rooms or "cells" in a monastery (see Figure 3.4). These cells are defined as functioning units separated from the nonliving world.

Although it has progressed in design, materials, and technology, the compound light microscope is based on the same principle as in the 17th century: light bends as it passes through the specimen to create a magnified image. Some amount of light always bends

Figure 3.3 Compound light microscope – its parts and internal lens system.

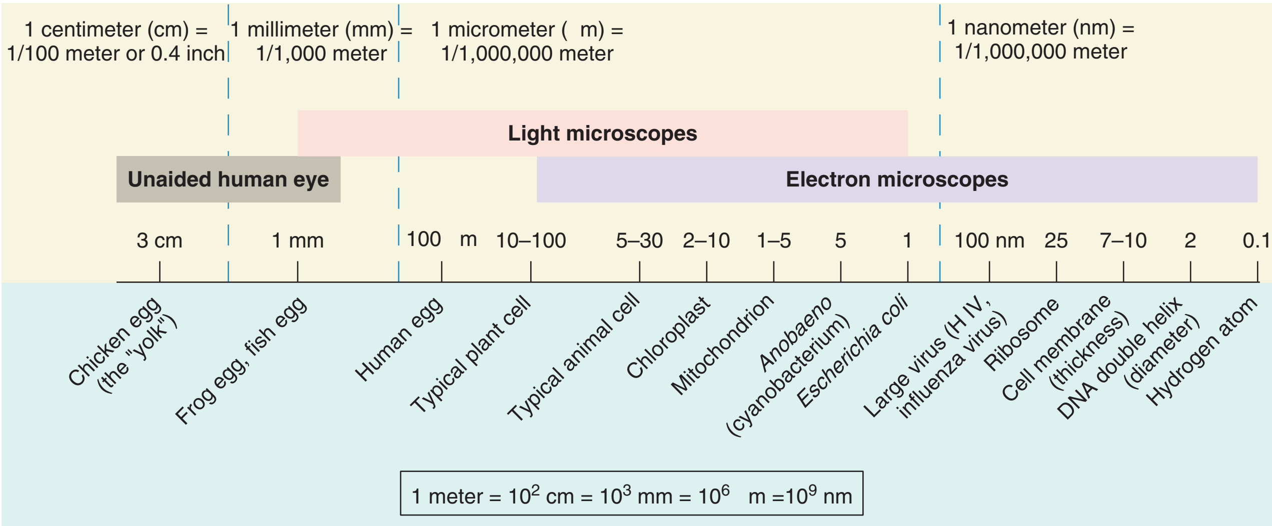


Table 3.1 Measurements Used for Microscopy. The units of measurement used in the study of molecules and cells correspond with methods by which we are able to detect their presences.

when hitting the edges of the lens, causing scattering in a random way. The random scattering of light, called diffraction is bad for getting a clear focus on the image. Diffraction also limits the resolution of the image. Resolution is defined as the ability to see two close objects as separate. (Think about looking at two lines on a chalkboard that is very far away; chances are they blur together and look like one messy line.) In fact, the human eye has a resolving power of about 100 μm or 1/10th of a millimeter for close-up images. In other words, two lines on a paper closer than 1/10th of a millimeter apart look blurry to us. The light microscope is limited in the same way by diffraction because the diffracted rays create blurry images.

Diffraction

The random scattering of light.

Resolution

Is the ability to see two close objects as separate.

Figure 3.4 Hooke's microscope from the 1600s and van Leeuwenhoek with his microscope. These simple microscopes led to the first descriptions of cells. Van Leeuwenhoek's microscope consisted of a small sphere of glass in a holder.

Higher magnification under the microscope leads to greater diffraction. This is the reason a compound light microscope can magnify only up to 1000–1500 times (under oil immersion), after which there is too much diffraction for a clear image to be formed. To overcome the effect of diffraction and achieve clarity at higher magnifications, oil is placed on the slide. However, even with oil immersion, only the large nucleus of a cell can be seen; other organelles appear as small dots or not at all.

So how did the more complex world of even smaller structures within cells get discovered? The 1930s saw the development of the electron microscope that allowed for magnifications of over 200,000 times greater than that of the human eye. There are two types of electron microscopes: transmission electron microscope (TEM) and scanning electron microscope (SEM). Transmission electron microscopy allows a resolving power of roughly 0.5 nm (see Table 3.1) that visualizes structures as small as five times the diameter of a hydrogen atom. Electron microscopes use electrons instead of light, which limits diffraction and increases resolution. Magnets instead of lenses focus electrons to create the image. The electrons pass through very thin slices of the specimen and form an image.

Transmission electron microscope (TEM)

A type of electron microscope that magnifies structures within a cell.

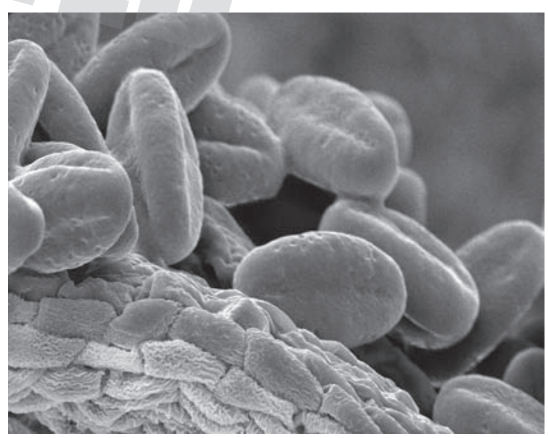
Scanning electron microscope (SEM)

An electron microscope that looks at the surfaces of objects in detail by focusing a beam of electrons on the surface of the object.

A SEM looks at the surfaces of objects in detail, while a TEM magnifies structures within a cell. The SEM has a resolving power slightly less than the TEM, at 10 nm. (A depiction of an electron microscope is shown in Figure 3.5.) Electron microscopy has led to many scientific developments, uncovering subcellular structures to help us understand cell biology. Seeing a mitochondrion enables us to better understand diseases and perhaps, if our opening story becomes reality, improve societal health through its use.

Cell Theory

Fairly recent advances in microscopy have allowed scientists to learn about the structure and function of even the tiniest components of cells, but the cell theory, which states key ideas about cells, developed a long time ago. We have seen that scientists began studying cells in the early 1700s. About a century later, in 1838, a German botanist named Matthias Schleiden (1804–1881) concluded that all plants he observed were composed of cells. In the next year, Theodor Schwann (1810–1882) extended Schleiden's ideas,



(b)

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Figure 3.5 b. Apple tree pollen grains on cells, an electron micrograph.

observing that all animals are also made of cells. But how did these cells come to survive generation after generation? The celebrated pathologist Rudolf Virchow (1821–1902) concluded in 1858 that all cells come from preexisting cells (He wrote this in Latin: "*Cellula e cellula*"). These scientists contributed, together, to the postulates of the **cell theory**. The cell theory is a unifying theory in biology that places the cell as the center of life and unifies the many branches of biology under its umbrella. The cell theory states that:

1) All living organisms are composed of cells.
2) The chemical reactions that occur within cells are separate from their environment.
3) All cells arise from other cells.
4) Cells contain within them hereditary information that is passed down from parent cell to offspring cell.

The cell theory showed not only that cells are the basic unit of life, but that there is continuity from generation to generation. Genetic material is inherited in what we refer today as the cell.

Types of Cells

Microscopes allowed researchers to examine differences between organisms that had previously been impossible to determine. A current classification of organisms defines five kingdoms, with organisms in those kingdoms having similar types of cells (There is some debate arguing inclusion of Archaea bacteria as a separate kingdom, and a six-system classification scheme is thus also accepted). Cells of organisms in the five kingdoms each have many internal differences, as summarized in Table 3.2. Images of some organisms of each kingdom are given in Figure 3.17 as examples.

Prokaryotes (bacteria) are composed of cells containing no membrane-bound nucleus and no compartments or membranous organelles. They are much smaller than eukaryotes, by almost 10 times. Prokaryotic genetic material is "naked," without the protection of a membrane and nucleus. They are composed of very few cell parts: a membrane, cytoplasm, and only protein-producing units called ribosomes. Even without most structures found in other organisms, prokaryotes contain genetic material to reproduce and direct the functions of the chemical reactions occurring within its cytoplasm.

Table 3.2 Differences in Cell Structure within the Five Kingdoms: Plants, Animals and Prokaryotes.

Group	Domain	Cell Type	Cell Number	Cell Wall Component	Energy Acquisition
Bacteria	Bacteria	Prokaryotic	Unicellular	Peptidoglycan	Mostly heterotrophic, some are autotrophic
Protists	Eukarya	Eukaryotic	Mostly unicellular, some are simple multicellular	Cellulose, silica; some have no cell wall	Autotrophic, heterotrophic
Plants	Eukarya	Eukaryotic	Multicellular	Cellulose	Autotrophic
Animals	Eukarya	Eukaryotic	Multicellular	No cell wall	Heterotrophic
Fungi	Eukarya	Eukaryotic	Mostly multicellular	Chitin	Heterotrophic

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Prokaryotes have a simple set-up, but all of the needed equipment to carry out life functions. Bacteria have a rapid rate of cell division and a faster metabolism than eukaryotes. Most organisms on Earth, in terms of sheer number, are prokaryotes.

- As indicated in Chapter 1, prokaryotes include organisms in the Bacteria and Archae domains. These organisms will be discussed further in Chapter 8.

All other organisms (plants, animals, fungi, and protists) are **eukaryotes**. Cells of eukaryotes are complex, containing a membrane-bound nucleus that houses genetic material. Eukaryotic cells comprise compartments that form a variety of smaller internal structures, or organelles. Eukaryotic cells are the focus of this chapter, which will give an overview of the primary organelles and their functions (Figure 3.6).

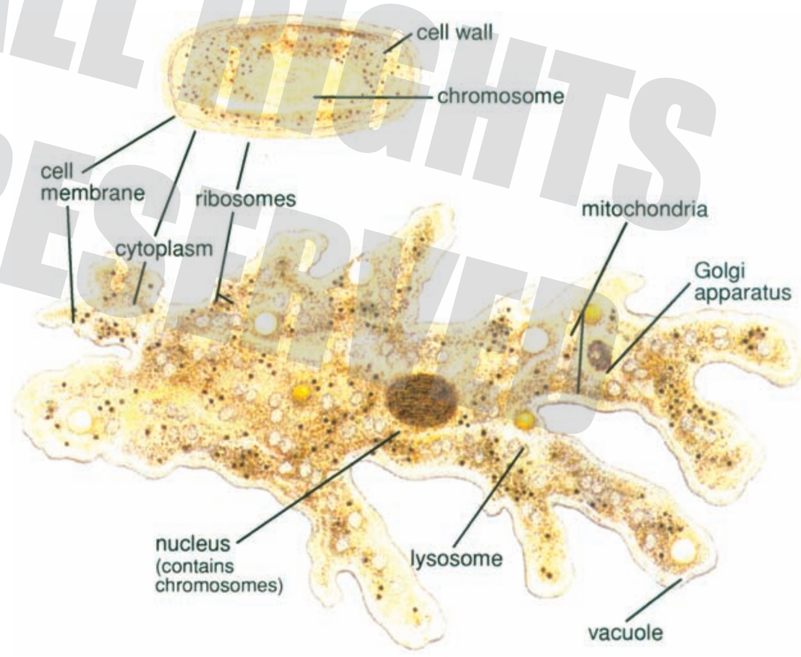
Eukaryotes may be examined by dividing into its four groups: plants, animals, fungi, and protists. Plants contain cells that are surrounded by a cell wall, a rigid structure giving its organisms support. Plant cells contain chloroplasts, which enable plants to carry out photosynthesis, using energy from sunlight to make food.

Photosynthesis

The process by which green plants use sunlight to synthesize nutrients from water and carbon dioxide.

- Plant cell walls contain cellulose, which gives structure to plants as discussed in Chapter 2. The process of photosynthesis, producing food for plants, will be further discussed in Chapter 4.

Plants also have large vacuoles or storage compartments to hold water and minerals for a plant's functions. While both plants and animals have a cell membrane, animal cells are



(a)

Figure 3.6 a. Differences between prokaryotes and eukaryotes. Prokaryotes have a generally simple structure (see top cell in figure above), while eukaryotes (the lower cell in figure above) have multiple organelles and membranes forming complex compartmentalization. From *Biological Perspectives*, 3rd ed by BSCS. b. Differences between plants and animals. Plant and animal cells perform different functions, and their subcellular structures are also different. Plant cells have chloroplasts to produce sugar and a cell wall to give added strength. The animal cell shown has no cell wall or chloroplasts but possesses centrioles. From *Biological Perspectives*, 3rd ed by BSCS.

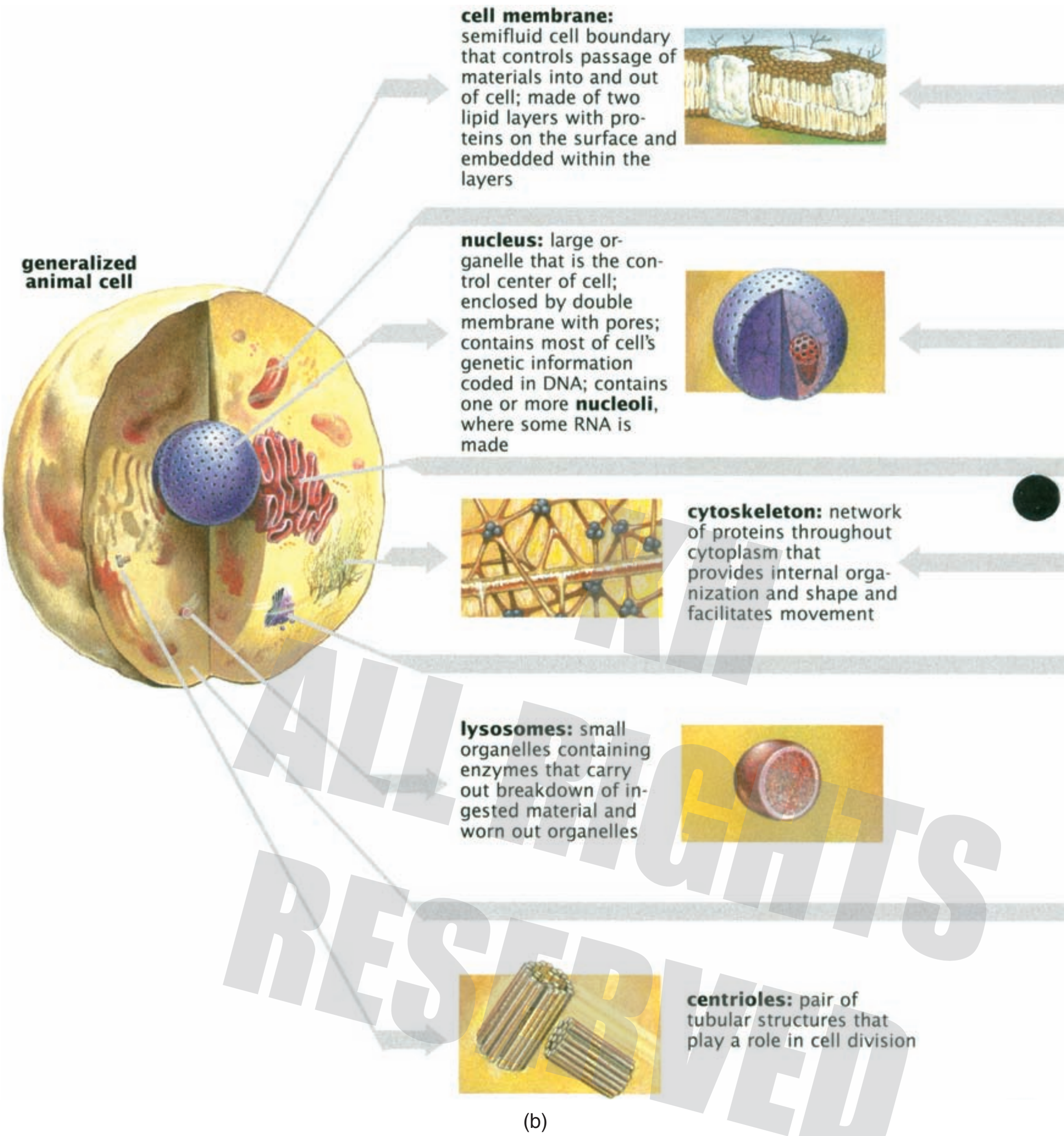


Figure 3.6 (*Continued*)

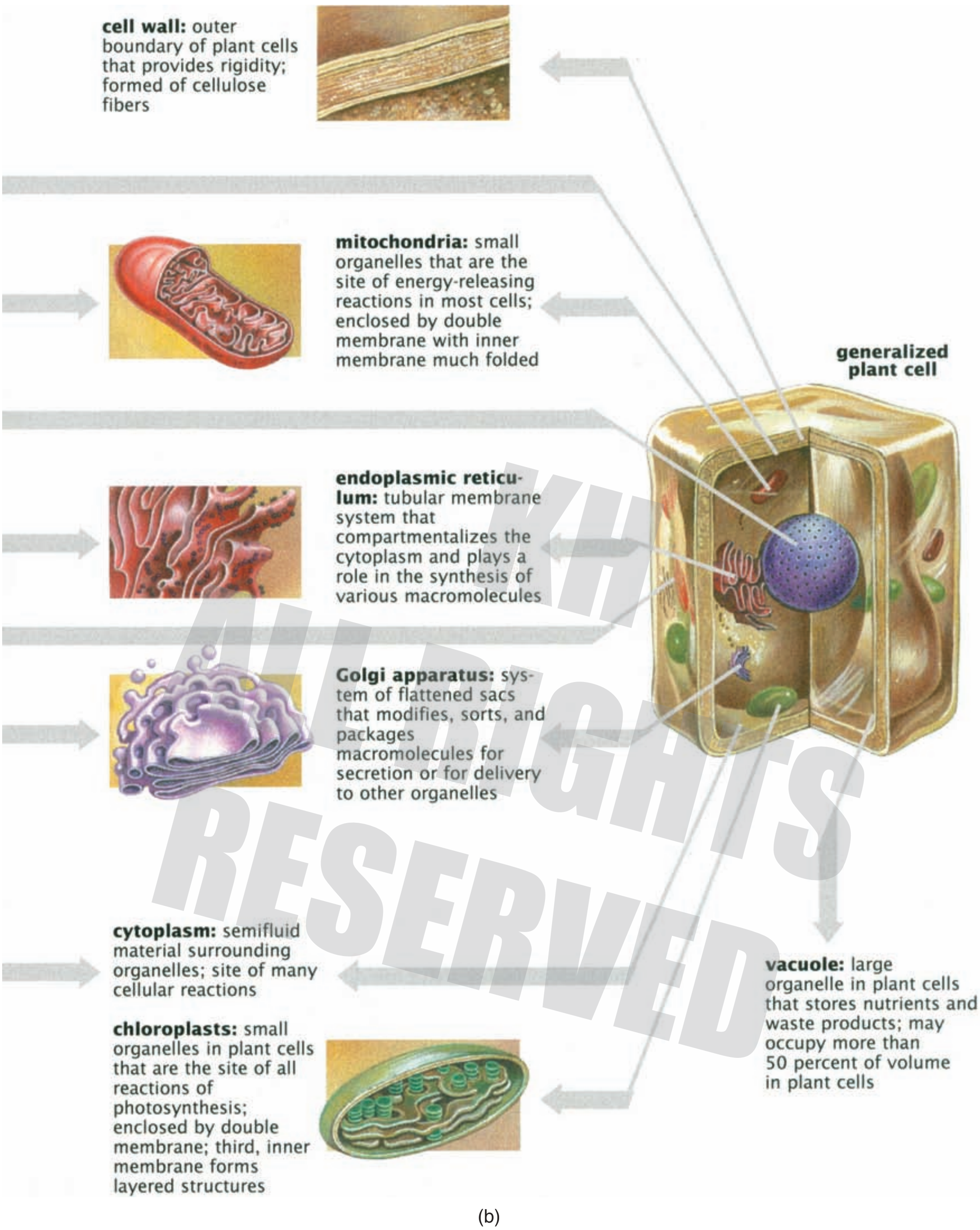


Figure 3.6 (*Continued*)

Centriole

Minute cylindrical organelles found in animal cells, which serve in cell division (not given in bold in text).

less rigid, surrounded only by a cell membrane and lacking a cell wall for support. Both plants and animals contain membrane-bound organelles, but animals also contain a set of small structures called centrioles, which serve in cell division. Animal cells are also quite complex, as we will see. While lacking certain organelles, such as cell walls and chloroplasts, they have flexible strategies to perform many functions.

Fungi have cell walls but no chloroplasts. They are not able to make their own food and, instead live off of dead and decomposing matter as well as other living organisms, to obtain energy. Mushrooms and yeasts are familiar types of fungi, which will be discussed in Chapter 7.

Some species of protists are a bit animal-like in that they are able to move; other species are a bit plant-like in that they have chloroplasts. Protists such as *Amoeba* in Figure 3.7 have varied environments. *Amoeba* live in freshwater and, in a rare infectious disease, grow and destroy human brain cells. We will discuss protists in more detail in a later chapter.

The kingdom **Plantae** contains the plants—multicellular organisms composed of eukaryotic cells that live by manufacturing high-energy organic molecules through the process of photosynthesis. Included are **r** moss (*Polytrichium*); **s** club moss (*Lycopodium*); **t** horsetail (*Equisetum*); **u** grape fern (*Botrychium*); **v** pine (*Pinus*); **w** corn (*Zea*); **x** Jacob's ladder (*Polemonium*); **y** tiger lily (*Lilium*).

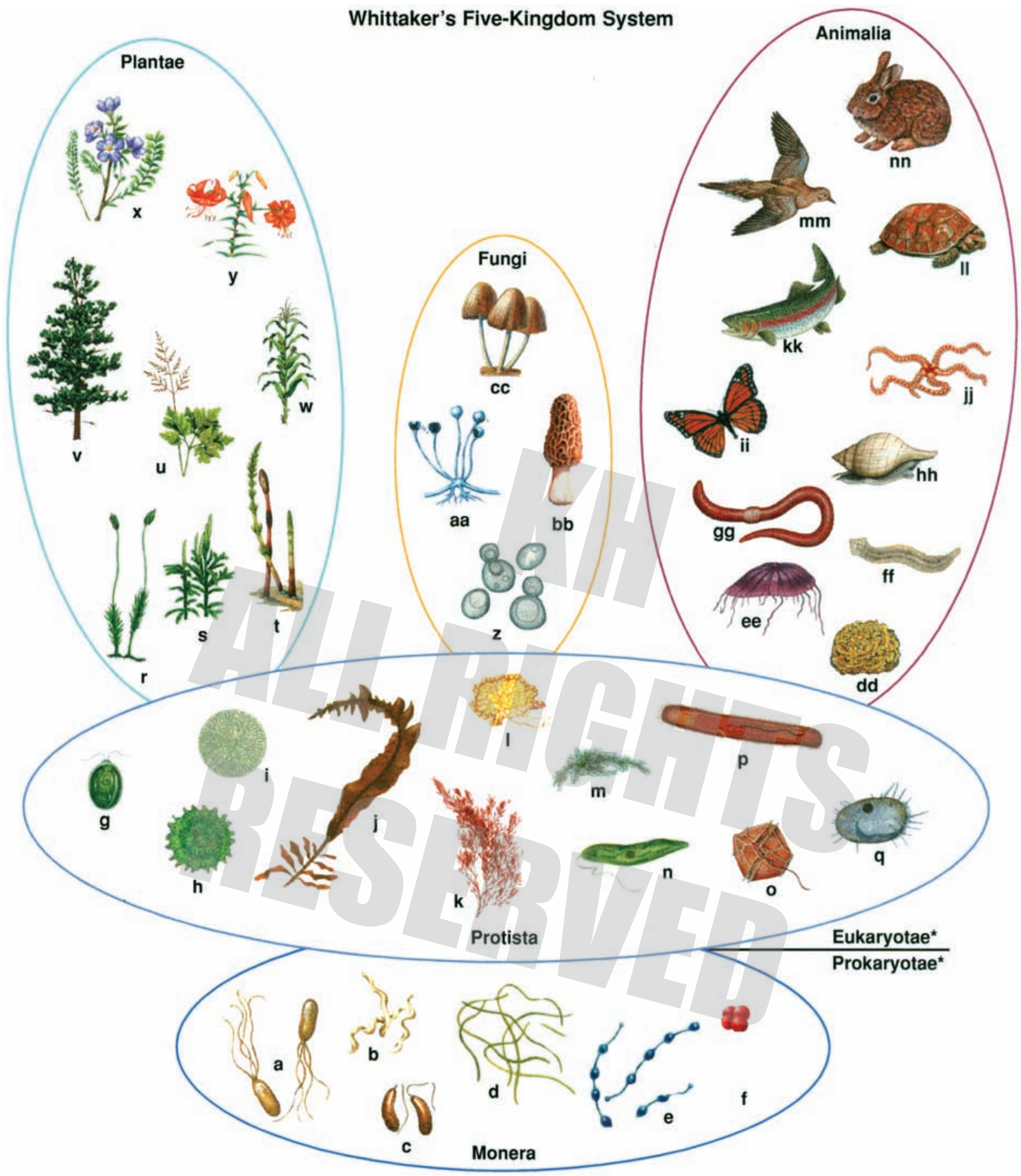
The kingdom **Fungi** includes eukaryotic, typically multicellular, organisms such as mushrooms and molds that live by absorbing organic molecules from the environment. Examples shown are **z** yeast (*Saccharomyces*); **aa** bread mold (*Rhizopus*); **bb** morel (*Morchella*); **cc** mushroom (*Coprinus*).

The kingdom **Animalia** consists of animals—multicellular organisms composed of eukaryotic cells that live by consuming other organisms as their source of organic molecules. We show **dd** sponge; **ee** purple jelly; **ff** planarian (*Dugesia*); **gg** earthworm (*Lumbricus*); **hh** snail; **ii** viceroy (*Limenitis*); **jj** brittle star; **kk** trout (*Salmo*); **ll** turtle (*Gopherus*); **mm** mourning dove (*Zenaida*); **nn** rabbit (*Silvilagus*).

The kingdom **Protista** (sometimes called **Protoctista**) includes all eukaryotic organisms that are not classified as plants, animals, or fungi. Protists range in size from microscopic, one-celled organisms such as *Paramecium* to large, multicellular organisms such as the seaweed kelp. Multicellular algae like the kelp are usually classified as protists because they do not develop from embryos surrounded by parental tissues. Many biologists, however, feel they should be classified in the kingdom Plantae. Shown here are two green algae **g** (*Chlamydomonas*) and **h** (*Pediastrum*); **i** diatom (*Stephanodiscus*); **j** brown alga (*Alaria*); **k** red alga (*Polysiphonia*); **l** slime mold (*Physarum*); **m** entamoeba (*Amoeba*); **n** flagellate (*Euglena*); **o** dinoflagellate (*Gonyaulax*); two ciliates, **p** (*Spirostomum*) and **q** (*Euplotes*).

The kingdom **Monera** (now usually called **Prokaryotae**) contains the bacteria. Bacteria are one-celled microorganisms whose cell structure is prokaryotic. The examples shown are two gram-negative bacteria **a** (*Pseudomonas*) and **b** (*Spirullum*); **c** sulfur bacterium (*Desulfovibrio*); **d** cyanobacterium (*Oscillatoria*); **e** purple bacterium (*Rhodomicrobium*); **f** gram-positive bacterium (*Micrococcus*).

Figure 3.7 Cells of the five kingdoms. While the cells of organisms in all of the kingdoms perform similar life functions, their individual structures enable differing functions unique to each kingdom. From *Biological Perspectives*, 3rd ed by BSCS.



*__Prokaryotae__ have prokaryotic cells that lack a membrane-enclosed nucleus, whereas **Eukaryotae** have eukaryotic cells that *do* contain a membrane-enclosed nucleus. Note that all of the bacteria (Kingdom Monera) are prokaryotic; all other organisms are eukaryotic.

Figure 3.7 (*Continued*)

The Role of Inheritance

The stratification system depicted in our opening story is based on the inheritance of cellular components. We know that organelles are structures that carry out functions within a cell. In fact, organelles work in concert with one another, coming together to

THE OXYGEN REVOLUTION

Have you ever tried to imagine the Earth in its early stages? After millions of years during which the Earth was a mass of molten gases, those gases began to cool into layers that became landmasses, while water vapor formed seas. There were as yet no animals and only a few prokaryotic forms living in the waters. One form of bacteria, known as cyanobacteria, is believed to have been among the first organisms to photosynthesize (convert light energy into chemical energy to drive cellular activities). Since a by-product of many forms of photosynthesis is oxygen, over several million years, more and more oxygen was released into the atmosphere – the oxygen revolution.

The oxygen revolution occurred, according to geologists, about 2.5 billion years ago. It led to an availability of oxygen that could be used by cells that evolved to use it. The advantage of using oxygen to yield larger amounts of energy led to an increase in the number of aerobic cells. Aerobic cells, or those cells that use oxygen as the fuel for obtaining energy, contain mitochondria to provide large amounts of energy production. Over the course of many millions of years, single-celled eukaryotes, with more complex cellular processes than prokaryotes, evolved, then multicellular eukaryotes, and eventually organisms became larger and more complex. It is important to realize that oxygen is a key player in the development of organisms since it can be used to produce fast, plentiful energy.

Oxygen revolution

The biologically induced appearance of dioxygen in Earth's atmosphere 2.5 billions of years ago.

Aerobic

Occurring in the presence of oxygen or require oxygen to live.

form a complex, dynamic cell. Mitochondria, so important in the society in our story, are the powerhouses of the cell, providing energy for a cell's functions.

All organelles are built and controlled by inherited genetic material. Thus, the way a cell works is based upon its genetics. But some organelles are inherited separately from the others. There are three ways to inherit organelles, including mitochondria: 1) maternal inheritance, in which organelles are inherited from mothers; 2) paternal inheritance, in which organelles are inherited from fathers; and 3) bi-parental inheritance, in which organelles are inherited from both mothers and fathers. The inheritance type varies among species and for different organelles. For example, chloroplasts are paternally inherited in the giant redwood *Sequoia* but maternally inherited in the sunflower *Helianthus*. Most animal species have maternal transmission of mitochondria, as seen in the story, because female eggs hold most of the mitochondria in their large cytoplasmic cells. Sperm contributes very little cytoplasm or organelles in human species, although there are exceptions among other organisms; for example, green algae *Chlamydomonas* has paternal transmission of mitochondria.

Endosymbiosis

Eukaryotes appeared in Earth's history about 1.5 billion years after prokaryotes. In their 2.0 billion years on Earth, eukaryotes have evolved into living systems that range from butterflies to beavers, crocodiles to humans. As you progress through this text and the course, you will learn about how this amazing diversity evolved.

Eukaryotes have two types of organelles – those that evolved as membranes and those from other, simpler organisms as precursors, called endosymbionts. Endosymbionts

Endosymbionts

Any organism living in the body or cells of another organism.

have their own genetic material and are semi-independent within the cells of eukaryotes. Endosymbionts include two types of organelles – mitochondria and chloroplasts. Mitochondria are the energy producers of animal cells, and chloroplasts are solar power transformers of plant cells. Mitochondria divide independently and have an internal environment that is different from that in the rest of the cell.

Endosymbiotic theory

The theory that states that some organelles in eukaryotes were descendants of ancient bacteria that were absorbed by larger cells.

Evidence tells us that endosymbionts were once independent prokaryotes that were somehow incorporated into eukaryotic cells. Lynn Margulis, a well-known evolutionary biologist, formulated the endosymbiotic theory, which states that some organelles in eukaryotes were descendants of ancient bacteria that were absorbed by larger cells. (*Symbiosis* refers to a mutually beneficial relationship of organisms living together; *endo* means within.) The larger cell gave ancient bacteria absorbed by larger cells a "home." The bacteria received protection and in return gave their unique set of chemical reactions to the larger host cell.

Analysis of endosymbionts have particular uses in today's society: Crime scene investigations can test for mitochondrial DNA; ancestry can be traced using mitochondrial DNA; and research on diseases inherited due to faulty mitochondrial genetic material may yield medical treatments. In our story, Joules and Theta had a different form of mitochondria than Sally. Joules, Theta, and Sally all inherited their mother's mitochondria, but Sally's inheritance included a predisposition for a number of diseases.

Cell respiration

A series of energy-producing reactions that convert food energy into ATP.

Chloroplast

A part of plant that contains chlorophyll and conducts photosynthesis.

We have said that mitochondria can be thought of as the power plants of the cell. We say this because mitochondria carry out the series of energy-producing reactions that convert food energy into ATP (defined in Chapter 2; the form of energy used to drive cell functions). This set of reactions is called cell respiration.

Chloroplasts may have originated from cyanobacteria, which were able to transform light energy into usable sugar for energy in the process called photosynthesis – the making of food (glucose) from sunlight, carbon dioxide, and water. Thus, precursor mitochondria provided instant ATP energy for animal host cells, and ancient chloroplasts made stored glucose available for longer-term use in plants. Modern chloroplasts use sunlight to rearrange carbon to form food in the form of sugars, for cell usage. They are the solar power plants of cells because they trap sunlight and generate ATP energy.

- These energy-obtaining processes, cell respiration, and photosynthesis will be discussed in greater detail in Chapter 4.

Evidence for mitochondria and chloroplasts as endosymbionts is considerable:

1) Mitochondria and chloroplasts are similar in size and shape to bacteria, roughly 7 µm in length.
2) Both contain their own genetic materials and divide in the same way as prokaryotes, through binary fission (splitting in half).
3) Both contain the same type of 70S ribosomes (described below; small organelles that make protein) as bacteria, whereas eukaryotes contain 80S ribosomes.
4) Mitochondrial and chloroplast DNA are more related to bacterial than to eukaryotic DNA. See the proposed process on endosymbiosis in Figure 3.8.

We will now look at each of the structures of the cell, using the analogy of a city, with the organelles being structures critical to the smooth functioning of the "city." Organelles work in concert with each other to carry out life functions. Chloroplasts and mitochondria carry out key energy-producing and releasing functions to drive cell activities. However, there is an intricacy to cell biology akin to the workings of a large and dynamic city.

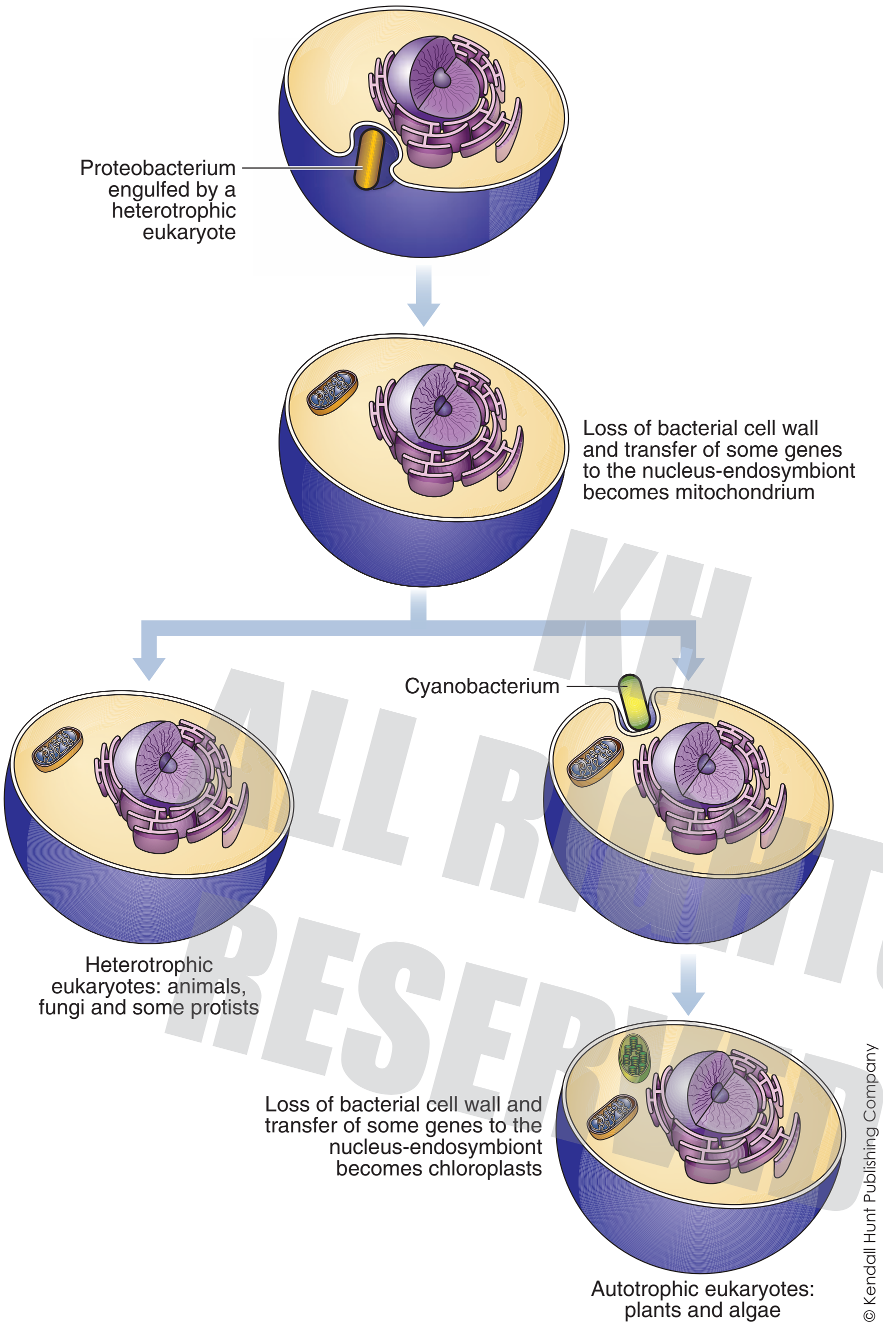


Figure 3.8 This model shows how mitochondria and chloroplasts wound up in eukaryotic cells. Evidence for endosymbiosis. Chloroplasts and mitochondria are similar in size and shape to bacteria. The ribosomes in bacteria and mitochondria and chloroplasts are "70S." Most bacteria have a size of roughly 7–10 μm and 70S ribosomes, both characteristics are similar to mitochondria and chloroplasts.

Cell Architecture: The Cell As a City

Plasma (cell) membrane

A biological membrane that separates the cell's interior from the outside environment.

Selectively permeable

A condition in which the membrane allows some materials to pass through cells but not others.

Cytoplasm

A semisolid liquid that holds organelles suspended within it.

The organelles of a cell work independently but in concert, with its components interacting actively, having many thousands of chemical reactions occurring at any one time. In an analogous way, the components of a city work independently but cooperatively to ensure its smooth functioning. The structures in the cell are shown in the cartoon image depicting the cell as a city in Figure 3.9.

A cell membrane or plasma membrane surrounds each cell, which is a wrapping that allows some materials across it. While all cells contain a plasma membrane, some cells have structures surrounding the membrane for protection and support. For example, plant cells have cell walls surrounding their membranes, and fungi have chitin barriers, which are protective polysaccharides.

Plasma membranes are important to living systems because they control the materials entering and leaving them. Plasma membranes are selectively permeable. *Selective* permeability means that the membrane allows some materials to pass through cells but not others. Within the cell is the cytoplasm, a semisolid liquid that holds organelles suspended within it. Cytoplasm is roughly 60–80% water by volume, and chemical reactions occur within its medium. The other 20–40% of cytoplasm is composed of proteins and dissolved ions. Cytoplasm is all of the cell material found between the plasma

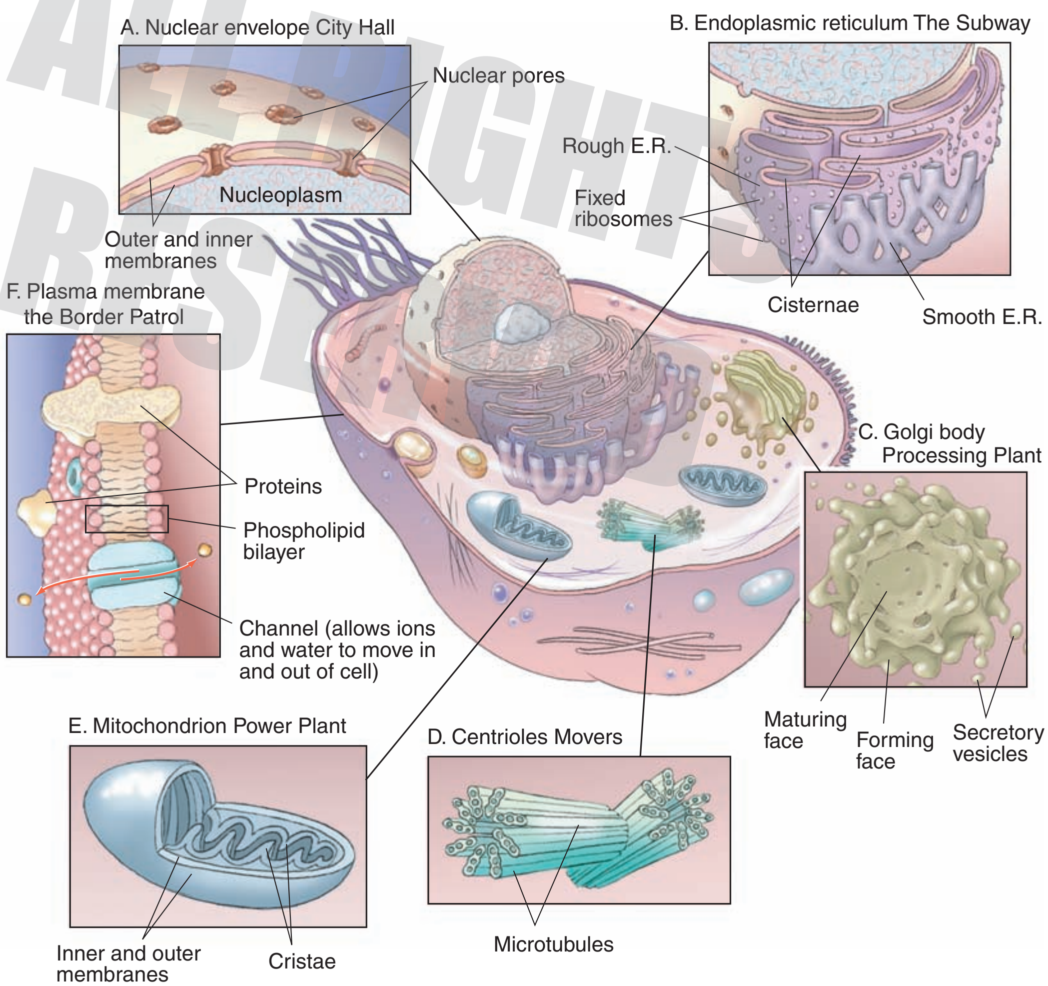


Figure 3.9 A cell is like a city. Its parts work together to perform a cell's function.

membrane and the nucleus. A nucleus, or control organelle, serves as the city hall of the cell, usually centered within cytoplasm. It contains the genetic material that produces and controls the cell's parts.

A cell's architecture is very complex, with continual activity within many compartments of each cell. Compartmentalization of a cell is accomplished by a series of membranes throughout its cytoplasm. These membranes allow for a surface to perform chemical reactions such as those carried out by enzymes. The layers of membranes also separate different chambers of the cell so that conditions may be different within each chamber. An acidic pH in one compartment, for example, may be suitable for cell functioning in one section, while a basic pH might be needed in another section. Throughout the cell, ropes (such as collagen and elastin) and membranes maintain a cell's organization. Figure 3.9 gives you an idea of the complex architecture of the cell.

Nucleus

The central and the most important part of a cell and contains the genetic material.

Compartmentalization

The formation of cellular compartments.

Plasma Membrane: The "Flexible" Border Patrol

A border surrounds all cells: in eukaryotic animal cells, the border is the plasma or cell membrane. This dynamic covering is very complex, with parts that continually move to allow certain materials into the cell and keep other substances out. The plasma membrane is composed of a **phospholipid bilayer** in and around which are **membrane proteins** (see Figure 3.10).

- Recall from Chapter 2 that phospholipids are molecules with a phosphate (hydrophilic) head and two tails made of carbon and hydrogen atoms.

The phospholipids are arranged as a bilayer, with the heads facing to the outside and tails to the interior of the cell. The membrane proteins are part of the plasma membrane border, moving in between cholesterol molecules and phospholipids. Although it may seem that they are arranged randomly, in fact, they form a pattern. The membrane is often referred to as a fluid mosaic (see Figure 3.11) because it is made of different pieces that form a pattern and seem to float and move in the watery environment. Note the phospholipid bilayer in Figure 3.11.

There are two types of membrane proteins suspended within the phospholipid bilayer: integral proteins, which span the entire lipid bilayer; and peripheral proteins, which station either inside or outside of the membrane. Integral proteins are also known as **transmembrane proteins**. These membrane proteins serve to anchor cells to each

Fluid mosaic model

A model that describes the structure of cell membranes.

Integral protein (transmembrane or carrier protein)

A type of membrane protein permanently embedded within the biological membrane (not given in bold in text).

Peripheral protein

Is a protein that adheres only temporarily to the biological membrane with which it is associated.

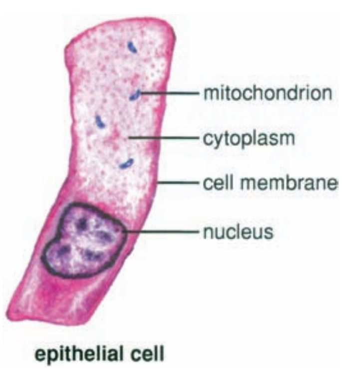


Figure 3.10 Every living cell is surrounded by a cell membrane. From *Biological Perspectives*, 3rd ed by BSCS.

other, move materials, much like a ferry, across the membrane, receive chemicals such as hormones, and transport ions through pores within them. These proteins orient themselves according to the bonds they make with surrounding chemicals.

Integral proteins in the fluid mosaic model serve four functions:

Receptor

A structure of the cell's surface that selectively receives and binds a specific substance.

Recognition protein

A protein type functioning as binding site for hormones.

1) As receptors, allowing chemicals to bind to cell surfaces. Insulin, a hormone-regulating blood sugar, binds to cells to increase the absorption of sugar from blood into cells. Insulin's special shape matches to the shape on integral proteins. The docking of the two elicits chemical reactions within the cell to maintain sugar balance;
2) As recognition proteins, giving the immune system a code that informs it that a cell is its own and not a foreign substance. Cells with the wrong recognition proteins are rejected, as occurs in cases of organ transplants whose codes do not match up with those of the recipient;
3) As **enzyme surfaces**, facilitating various chemical reactions occurring on the surface of a cell. Enzymes assist in the digestion of certain nutrients, the first step in allowing nutrients to be absorbed; and
4) As **transport proteins**, moving material across a membrane.

Transport proteins act as a sort of flexible border-patrol system, which allows some materials to pass through the membrane while keeping others out. This border-patrol system is an important part of the cell as a city. The size, shape, and chemistry of substances attempting to move into and out of cells determine which materials pass through the plasma membrane. Fatty materials pass through the membrane easily. For example, ethanol in alcoholic drinks easily passes through membranes because it also dissolves in fats. It is absorbed through the phospholipid bilayer and quickly giving a "high" to a person after drinking. The interior of the lipid bilayer is hydrophobic, so it avoids water and dissolves other substances that avoid water. Thus, only other hydrophobic, usually fatty or fat-soluble, materials may pass easily through the bilayer.

Integral proteins of the membrane allow certain nonfatty materials, including smaller charged or polar particles to move through the lipid bilayer directly. These include chemicals such as oxygen (O_2), carbon dioxide (CO_2), and ammonia (NH_3). The quick movement of these materials is essential for life functions. For example, NH_3, a nitrogenous waste that builds up within all cells, needs to be rapidly removed.

Thus, integral membrane proteins serve to facilitate movement of materials that cannot easily pass across the membrane. Integral proteins move nonfatty materials across the membrane, such as sodium ions Na^+ and potassium ions K^+. Larger polar molecules, such as amino acids and glucose, also move through polar (or charged) channels within integral proteins. Channels that are polar are thus hydrophilic, allowing materials with a charge to pass through. Some substances use carrier proteins as pumps for transport, as is the case for the very important ions sodium (Na^+), potassium (K^+), and calcium (Ca^{+2}).In the case of the movement of water (H_2O), the most abundant chemical in living systems, it was recently determined from studies on **aquaporins**, or integral proteins with channels within them, that water presses its way through the bilayer using integral proteins. Sometimes water moves directly across the lipid bilayer by "wiggling" type motion to press itself through. Physical forces drive this movement.

As shown in Figure 3.11, short carbohydrate chains jut out from the plasma membrane. These serve as a recognition code for the immune system of animals. Embedded within the phospholipid bilayer of animal cells, cholesterol binds together molecules, helping to maintain the flexibility and motion of the membrane.

Consider for a moment, how many different pieces make up the plasma membrane, and you can see why it is called a mosaic. It is called a fluid mosaic because it

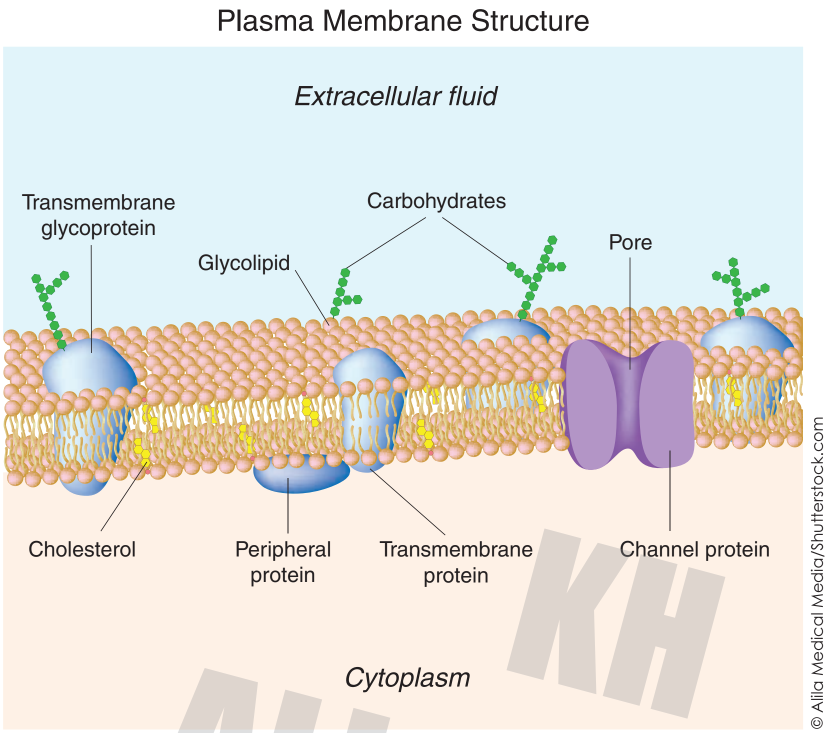


Figure 3.11 Cell membrane structure. The cell membrane is composed of a phospholipid bilayer with proteins embedded. Phospholipids are composed of two parts – a phosphate head which attracts to water (hydrophilic) and fatty acid tails which repel water (hydrophobic). Proteins are embedded within the lipid bilayer and each type performs a specific function.

is constantly moving, docking proteins, transporting materials, and changing its shape with the movements of a cell. Membranes are also found throughout the cell's structure, with transport occurring continually across different areas. The types of transport will be discussed later in the chapter. First, let's explore the structure surrounding plasma membranes in some organisms.

Walls of the City

What other borders exist around cells? Cell walls are found outside of plasma membranes in plants, fungi, prokaryotes, and many protists, particularly in algae. For example, single-celled algae known as dinoflagellates acquire their shape from their cell walls. Cell walls give protection to the material within cells and add to their structure. Cellulose, composed of large combinations of glucose units, polysaccharides, and lignin (a type of chemical cement), makes up the stiffening agent of plant cell walls. While plants contain cellulose, fungi cell walls contain chitin, also found in insect bodies and shells of some marine organisms. Cell walls are not found in animal cells, which have no need for a stiff structure that would prevent movement and flexibility. The cell walls of plants are shown in Figure 3.12.

Cytoskeleton: The City Scaffolds

The shape of a cell is also determined by the skeleton within a cell's cytoplasm, called its cytoskeleton. You may be surprised to learn that the cell itself has a skeleton made up of three types of fibers: microtubules, microfilaments, and intermediate fibers. All three

Microtubule

Is a larger filament structure that helps whole cells move.

Microfilament

A cytoskeletal fiber used for muscle movement.

Intermediate fiber

The smallest fibers of the cytoskeleton, which circulate materials within a cell.

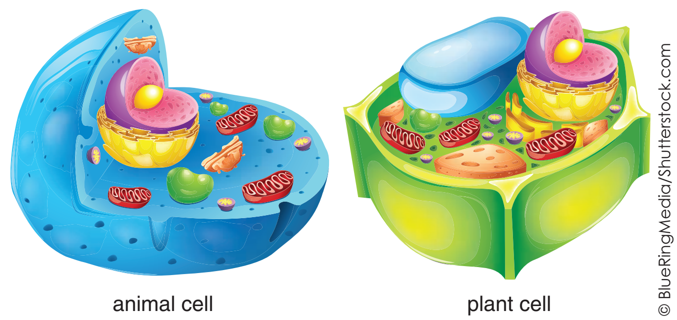


Figure 3.12 Plant cell wall. A rigid cell-wall composed of lignin and other stiffening materials maintains structure in plants. Animal cells have only a thin cell membrane, which gives almost no structure to the cell.

Cilia

Are short extensions that help cells move.

Flagella

Are long, whip-like extensions on a cell's surface that help in the movement of cells.

Intracellular transport

A process in which microfilaments circulate materials within cells.

fibers are made up of chains of twisted proteins that serve to link and support parts of a cell (see Figure 3.13). If the cell were a city, its cytoskeleton would be its infrastructure or scaffolding.

Microtubules form larger structures – cilia and flagella – that help whole cells move. Cilia are short extensions, and flagella are long, whip-like extensions on a cell's surface. Many types of organisms use cilia or flagella. A particular bacterium, *Proteus mirabilis*, has numerous and extravagant flagella arrangements. Flagella are found in humans only on sperm cells, to propel sperm toward their goal: the female egg.

Microfilaments, another cytoskeletal fiber, are used for muscle movement. Muscles contract with the help of microfilaments moving in a sliding motion. Microfilaments also circulate materials within cells, in a process called intracellular transport. Intracellular transport moves materials around the cell in a wavelike motion, adding

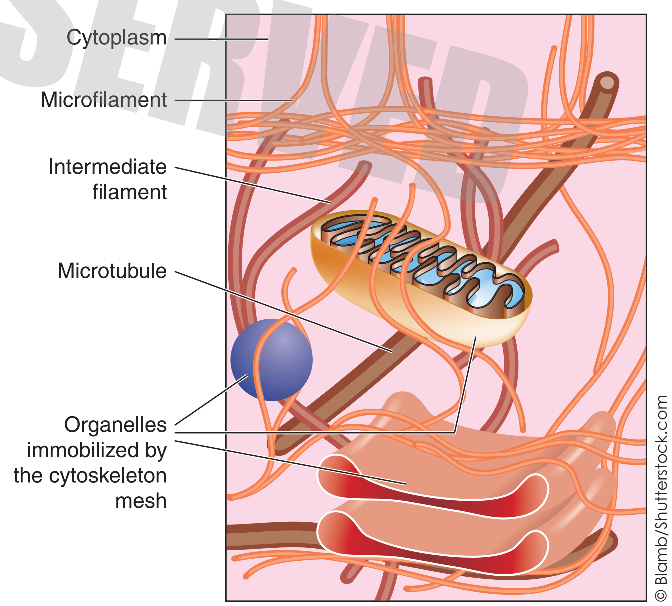


Figure 3.13 The internal skeleton of the cell. The cytoskeleton is composed of three types of fibers: microtubules, microfilaments, and intermediate fibers. Cell parts are held in place by the cytoskeleton and chemical reactions that occur on its scaffolding. The cartoon image in the figure shows the cytoskeleton of an animal cell.

efficiency to internal transport. Microfilaments greatly aid how materials are moved inside cells.

Intermediate fibers, the third type of cytoskeletal fiber, join cells together, especially for muscles such as the heart, where there is a great deal of pressure. Intermediate fibers are made of fibrous proteins, whereas, the other cytoskeleton fibers are composed of globular proteins.

- Fibrous proteins are not easily disassembled as described in the protein section of Chapter 2.

All three fibers anchor organelles in place, such as the mitochondria discussed in our opening story, within the cytoplasm. The cytoskeleton gives a solid framework on which chemical reactions take place. Some chemicals move along their fibers from one location in a cell to another. But overall, the cytoskeleton is not a permanent structure, as the name "skeleton" implies. Much like the plasma membrane, the cytoskeleton changes and reforms with the needs of a cell.

Nucleus: A City's City Hall

The most important membranous organelle is the nucleus, the control center of the cell. In our analogy of the cell as city, the nucleus is City Hall. The source of its leadership is DNA (deoxyribonucleic acid), the master planner for the organism. The nucleus is especially protected more than any of the other organelles, guarding its vital components. Thus, it is composed of a double membrane, called the nuclear envelop, with special pores or holes that have an octagonal shape and are highly selective. Only certain materials may pass through the nuclear membrane because the pores are very narrow.

In order to communicate with the cytoplasm and the outside world, DNA in the nucleus sends its messenger chemical RNA (ribonucleic acid) out through nuclear pores. RNA directs the synthesis of proteins, which in turn controls cell functions and the building of cell structures. A nucleus is shown in Figure 3.14.

In most organisms, DNA is inherited from both father and mother through genetic material stored and transmitted from nucleus to nucleus. Unlike in our story, which deals with the maternal lineage of mitochondrial DNA, nuclear DNA is obtained from the egg of one's mother and the sperm of one's father in sexually reproducing organisms. When cells are not dividing, DNA is coiled around **histone proteins**, which are a group of five small round proteins bound together with DNA in eukaryotes, together forming chromatin (Figure 3.15).When a cell divides, its DNA coils more tightly to histones, forming a shorter and thicker mass called chromosomes.

Nuclear envelop

The double membrane that protects the nucleus.

Chromatin

Is a complex of macromolecules found in cells and consist of protein, RNA, and DNA.

Chromosome

A thread-like structure formed when a cell divides and its DNA coils more tightly to histones.

Ribosomes, the City's Factory

The nucleus also contains large bodies called nucleoli (see Figure 3.16), which are special regions of DNA that clump together and produce small, spherical organelles known as the ribosomes. Ribosomes are made up of **RNA**. Ribosomal RNA directs the production of proteins, guided by the RNA message sent out of the nucleus from DNA. Ribosomes are the protein factories of the cell and thus you might think of them as the manufacturing plants of the cell city. RNA carries a message that is translated on the ribosome. This message gives the type of protein ordered by DNA in the nucleus. These processes of protein manufacturing will be discussed further in a later chapter.

All organisms require proteins and thus all living systems contain ribosomes. Bacterial ribosomes are lighter than eukaryotic ribosomes, but all ribosomes make proteins in the form of strings of amino acids. Proteins comprise so many cell activities and structures that ribosomes are essential organelles found in all living organisms.

Nucleoli

A small, dense round structure found in the nucleus of a cell.

Ribosome

Small, spherical organelle that is the site protein synthesis.

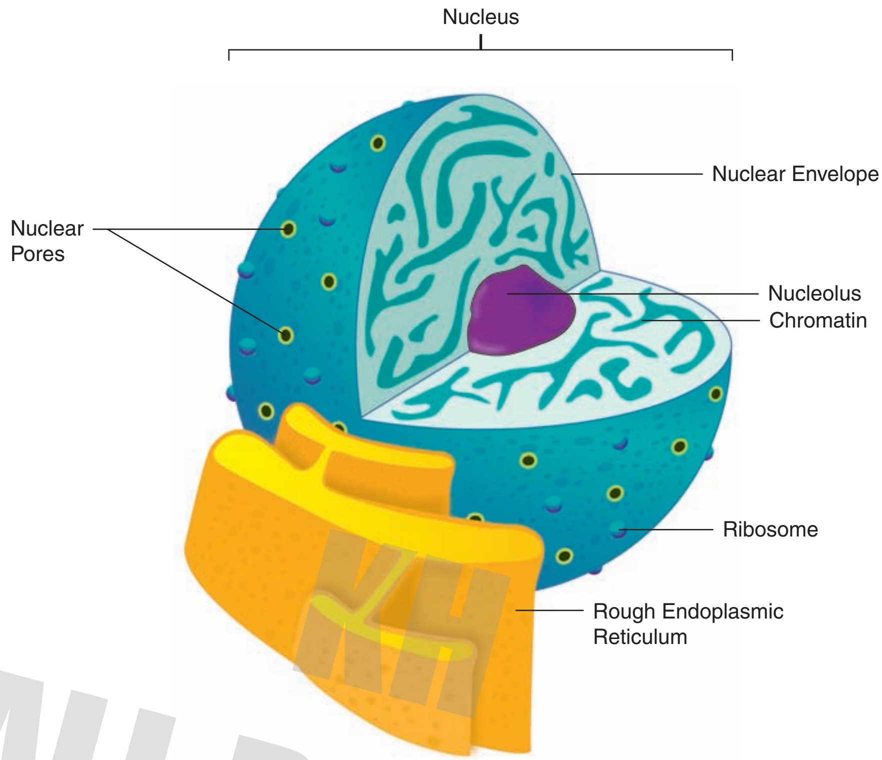


Figure 3.14 The cell nucleus and its components. The nucleus is the control center of a cell. It communicates with the rest of the cell by directing the production of proteins. Proteins serve many roles, particularly in chemical reactions. Vesicles transport materials from the nucleus to other parts of the cell and to the exterior through its endoplasmic reticulum.

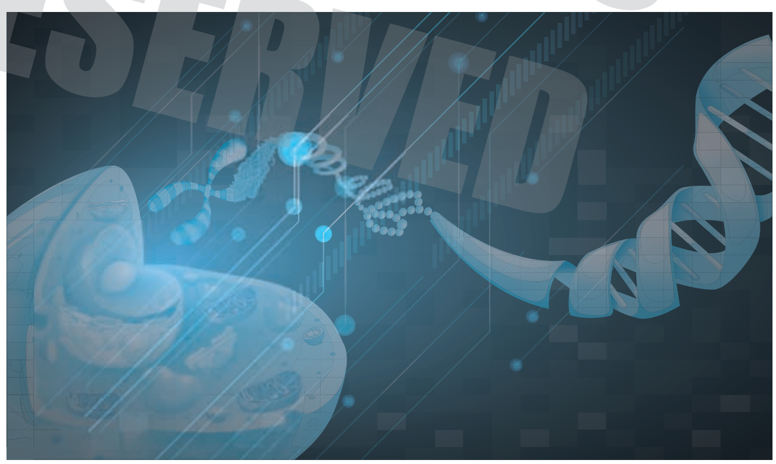


Figure 3.15 DNA coils around histone proteins, with large amounts of genetic materials becoming packaged into very small units.

Endoplasmic reticulum (ER)

Is a system of interconnected membranes that form canals or channels throughout the cytoplasm of a cell.

Endoplasmic Reticulum: A City's Subway

Ribosomes may be found freely within the cytoplasm or attached to membranes of other organelles. One organelle that often has ribosomes on its surface is the endoplasmic reticulum or **ER** for short. You can think of the ER as the subway system of the cell city.

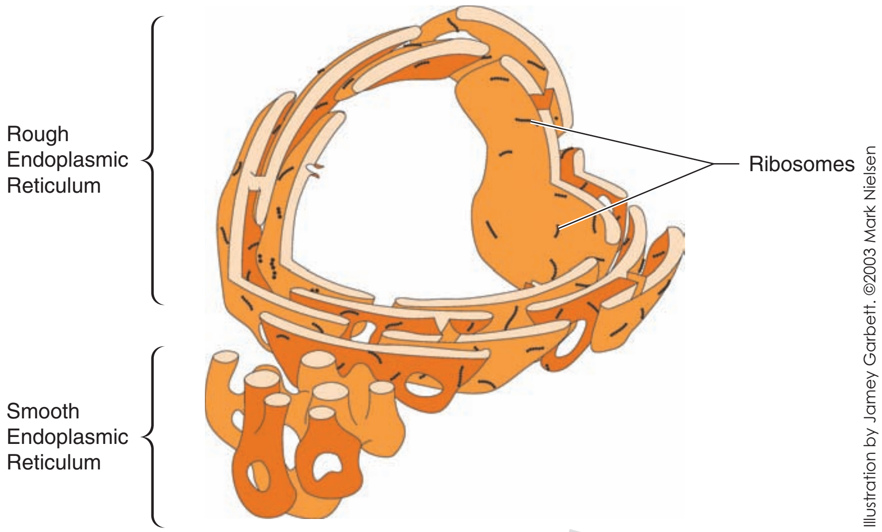


Figure 3.16 Smooth and rough ER. Rough ER has ribosomes attached to it, and smooth ER does not have ribosomes attached. Both act as the subway of the cell, transporting materials.

The ER is a system of interconnected membranes that form canals or channels throughout the cytoplasm of a cell. Materials are transported rapidly through the ER. Ribosomes found on ER surfaces dump newly produced proteins into the channels, allowing them to be transported to areas of a cell that need them. ER with ribosomes attached is called **rough ER** because it is rough in appearance. ER without ribosomes attached is termed **smooth ER** due to its undotted appearance. Figure 3.16 shows images of both smooth and rough ER

Rough ER is found in cells that export large amounts of protein, such as pancreatic cells that produce the protein-based hormone insulin. Smooth ER is a main component of organs that produce lipids, because it has enzymes that help in their manufacture. Organs (both testes and ovaries) that produce lipid-based sex hormones have smooth ER. Cells that manufacture and export lots of fatty material have elongated smooth ER.

Golgi Apparatus: A City's Processing Plant

When materials are transported out of the ER, they are often not fully processed and need the addition or removal of parts. The Golgi apparatus is the processing plant of the cell city that refines the materials passing through it. The Golgi apparatus consists of a series of four to six flattened sacs, resembling a stack of pancakes. The Golgi apparatus is shown in Figure 3.17.

Golgi apparatus

Is the processing plant of the cell city that refines the materials passing through it.

As processing occurs, the Golgi apparatus rearranges bonds, adds carbohydrates, or places a lipid on materials moving through. For example, the Golgi apparatus adds phosphate (glycerol) heads to lipid chains to form the phospholipids that make up plasma membranes. At the end of Golgi processing, vesicles or sacs are pinched off the export side. Vesicles are now ready for transport and contain needed materials for either within or outside of the cell. Certain vesicles are also made into another organelle, called the lysosome.

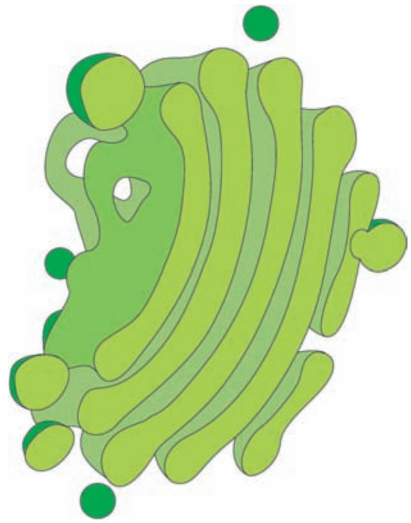


Figure 3.17 The Golgi apparatus processes materials such as a phospholipid as they pass through its sacs. A phosphate is added to a lipid molecule to produce a phospholipid for the plasma membrane. The golgi apparatus is the purifier of substances within a cell.

Lysosomes: A City's Police Officer

Lysosome

A small sac filled with digestive, hydrolytic enzymes enclosed in a membrane.

The lysosome, a small sac filled with digestive, hydrolytic enzymes, may be thought of as the cell's police officer.

- The term *hydrolytic* refers to hydrolysis, the breakdown of substances (described in Chapter 2).

Intracellular digestion

The process of breakdown of substances within the cytoplasm of a cell.

Lysosomes are found throughout the cytoplasm. They act as defenders of cells, just like police officers do. When invading microbes enter cells, lysosomes fuse with the "enemy" to digest it. Their contents break down materials within cells, and thus they are responsible for intracellular digestion. Consider the *Amoeba* (Figure 3.18) that is taking in food. Lysosomes act as its entire digestive system, fusing with a food particle and breaking it down.

Thus lysosomes are the police officers of the cell city, continually breaking down those substances that need to be removed and cooperating with the immune system to defend against invaders.

Lysosomes also play a critical role in reorganizing material. For example, did you know that our fingers and toes were fused together, or webbed, during our fetal development? Lysosomes digest the tissue between our digits, allowing fingers and toes to form. In roughly 1% of the population, lysosomes fail to fully digest this tissue, and fused toes or fingers are the result.

Tadpoles lose their tails during metamorphosis to adult frogs due to lysosome action that digests tails. Normal cell aging, or senescence, is a result of deterioration of lysosomes, according to one hypothesis. The deterioration of lysosomes releases their enzymatic contents, thereby digesting our cells from the inside out. Lysosomes normally have a double membrane, similar to the nucleus, giving double protection that limits such a disaster. The double membrane, however, cannot stand the effects of time, resulting in membrane failure and aging.

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Figure 3.18 Amoeba digesting food. The amoeba surrounds its prey, and lysosomes digest it.

There are 30 known inherited human diseases associated with the abnormal functioning of lysosomes. These disorders are called lysosome-storage diseases because in each case lysosomes lack a particular enzyme that breaks down substances that would normally be removed. These waste products build up in lysosomes, accumulating in cells. Tay–Sachs disease, commonly found in Ashkenazi Jewish populations, is a progressive and fatal disease in which fatty substances build up in tissues and nerve cells of the brain. There is blindness, mental deficiency, and death at an early age due to Tay–Sachs disease. Like most lysosome storage diseases, Tay–Sachs disease has few effective treatments.

Lysosome storage disease

A group of 30 known inherited human diseases associated with the abnormal functioning of lysosomes.

Vacuoles: A City's Warehouse

Storage in cells is accomplished by **vacuoles**, which are single membrane structures that hold materials in a cell; they are the warehouses of the cell city. There are three types of vacuoles: food, water, and waste vacuoles, each holding what their name indicates. **Food vacuoles** bring materials to and from the plasma membrane, depending upon a cell's need for nutrients. Adipose or fat cells in humans contain food (fat) vacuoles that comprise up to 80% of the cell, with enormous capabilities for energy storage. Food vacuoles shrink or expand based on the amount of fat stored in adipose cells.

Waste vacuoles are temporary storage compartments that send materials directly to the plasma membrane for export. Nitrogen-containing compounds are regularly stored in waste vacuoles. Their accumulation is dangerous, which is a major reason untreated kidney failure is often fatal after only a few days. One nitrogenous waste, ammonia (NH^3), is particularly poisonous, as you can attest if you have handled household ammonia. Wastes are therefore exported from a cell as quickly as they accumulate.

Water vacuoles, which are storage vesicles for water, can also grow very large, especially in plants. They serve to give shape to a plant cell, exerting pressure from within the vacuole onto the plant cell wall. A special type of water vacuole, found in simple-celled organisms such as the *Paramecium* is called the **contractile vacuole**. The contractile vacuole has the unique ability to actively pump water out water of cells, acting as a mini-kidney. Its shape is shown in Figure 3.19, with a star-like appearance denoting its structure.

Paramecium

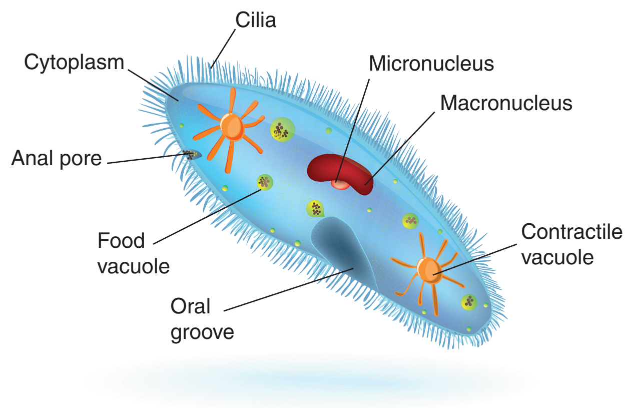

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Figure 3.19 The *Paramecium* has many of the structures found in protists. The contractile vacuole pumps excess water out of the paramecium.

Plastids: The Cell City's Paint Shops

Plastids are organelles that store special substances. They are found only in plants and algae. Colored substances called pigments are stored in some plastids. **Chloroplasts,** which contain chlorophyll, are the most well-known plastid.

- Chlorophyll is a green-colored pigment that will be discussed in Chapter 4.

Chromoplasts store yellow and orange pigments that give colors to trees, flowers, fruits and vegetables, such as carrots. **Leukoplasts** store starch and other food storage materials. Leukoplasts are usually found in roots, as in turnips and potatoes. We eat the starch-filled roots of these and several other foods.

Cell Junctions: The City's Bridges

In the same way that cities have bridges to connect and support their parts, cells contain cell junctions. Cell junctions serve a cell by providing areas of extra support, enabling communication between cells and preventing leaking through their borders.

There are three different types of connections or bridges between cells, each playing a needed role in particular cases. The first type of cell junction called desmosomes are anchoring junctions or spot welds between cells. You can think of desmosomes/anchoring junctions as the reinforcing rods embedded in concrete slab bridges of a city. Within desmosomes, intermediate fibers entangle with linker proteins and attach to a thickened region of the plasma membrane to give extra support in holding cells together. Heart or cardiac cells contain many desmosomes to withstand the pressure of millions of heartbeats.

The second type of cell junction, tight junctions, fuses areas together to prevent leaking and act as sealants. Intestinal cells have tight junctions to prevent their contents from leaking out of the bodies of animals.

The third type known as gap or communicating junctions are channels that run from one cell into another to allow rapid transport. These bridges help cells communicate with

Plastid

Organelle, found only in plants and algae, which store special substances.

Chromoplast

An organelle that contains any plant pigment other than chlorophyll.

Desmosome

One of the three types of connections between cells, is a cell structure specialized for cell-to-cell adhesion.

Tight junction

A specialized cell junction that fuses areas together to prevent leaking and act as sealants.

Gap (communicating) junction

Are channels that run from one cell into another to allow rapid transport helping cells communicate with other cells.

Figure 3.20 Cell junctions are connections between two different cities.

other cells. Embryonic cells have gap junctions because, in the absence of a developed vessel system for transport, an embryo compensates with gap junctions. The structures of cell junctions are shown in Figure 3.20.

Cell Shape and Size

Most cells in the body are round or spherical, except when a cell wall shapes a cell to conform to the forces around it. There are several reasons for the spherical shape, but resisting torque is a main one. Round surfaces resist the damaging effects of torque forces (circular forces). For example, consider a square cell, with edges that are likely to break off or become damaged when torque forces are applied to such cells. Any shape with a corner is more likely to be damaged than something that is spherical.

In senescence studies, the **wear-and-tear hypothesis** contends that damage due to forces placed upon living systems is a main reason for the aging of cells and the loss of cellular function. As a cell ages, it is more and more likely to succumb to the dangers and damages of the outside environment. Senescence is the loss of cell functions and in our story of Uncle Hans in Chapter 1, his dementia-related symptoms were a result of the loss of proper transmission of nerve signals within his brain. Senescence studies are continually looking at the damages to cells in attempting to reverse or slow the aging process.

There are many types of cells within multicellular organisms. As stated earlier, humans are constructed of about 200 different kinds of **somatic** or body cells. While they are each of very distinct types, with different characteristics, what is so surprising is their similarity. As discussed earlier, every cell has a control center to maintain the operations of the cell on a daily basis: a **membrane** that separates itself from the outside environment; and a semi-solid plasma, called **cytoplasm**, in which cellular activities occur. Most animal cells are between 10 and 30 μm in width, but can be as large as

Figure 3.21 Surface area of large cube vs. several smaller cubes of equal size. The surface area of the many smaller cubes is much greater than that of a single cube with a comparable volume.

100 µm (the size of a single grain of sand), as seen in the human egg or up to 1,500 µm as in frog's eggs. Eggs tend to be very large because they support a growing organism.

The small size of cells is explained by the **surface-to-volume hypothesis**, which states that the surface area (surface that is in contact with the outside environment) decreases rapidly in proportion to the volume of the cell. Thus, if the volume of a cell is too great, it cannot exchange enough of the materials (for example, oxygen) to support its size. The surface area of a variety of cubes that the little boy is hammering is shown in Figure 3.21. Note that the surface area of the single large cube is so much smaller than that of the aggregate of the many smaller cubes.

Another reason for limits on a cell's size and shape is its ability to control a large cell from a nucleus. Just as a long distance relationship is difficult due to distance, a cell too large has a more difficult time regulating activities of its structures from farther away. There are some organisms that have developed ways to adapt to these problems. A slime mold, shown in Figure 3.22 is, in fact, one giant, thin cell with thousands of nuclei strewn throughout its cytoplasm. In this way, it avoids the constant-volume problem by remaining thin for exchanges to occur and has control centers in enough areas to keep control efficient. Human muscle cells also are multinucleated and very large to perform their motility functions.

The Moving Crew: Rules and Procedures are City Law

The description of the cell's organelles and their functions provides a glimpse at how complex their structure is and how many functions they carry out. Physical laws govern how they interact to transport materials. Let's look now at a few of the basic laws of the city. The different transport types will be discussed according to their requirement for energy: 1) No energy needed: simple diffusion, facilitated diffusion, osmosis; 2) Energy needed: active transport, bulk transport (phagocytosis, pinocytosis, receptor-mediated endocytosis, and exocytosis).


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Figure 3.22 Slime molds. These organisms have multiple nuclei to control their large sizes. During some phases of their life cycles, they appear as gelatinous slime, giving them their infamous name.

Passive Transport

Passive transport involves the movement of materials without the use of cellular energy. Recall that the cell is bathed in water. Most atoms and molecules therefore exist as ions. Ions move constantly, jiggling, hitting one another, and forcing themselves farther and farther apart to fill the available space. The motion of each ion is driven by kinetic energy, or energy of motion. This kind of movement is called passive transport because it occurs naturally and spontaneously and again, requires no cellular energy.

Substances move apart during passive transport until they spread evenly through an area. This even level of dispersion is known as equilibrium. You have experienced this action of molecules if you have ever been in a bus or subway car with someone whose deodorant has failed on a hot day. The underarm odor is first detected by nearby passengers, but the smell can travel until it reaches even those people at the other end of the vehicle. Sweat odor molecules may travel in any direction at the same time. However, there is a net movement of smell molecules from an area of higher concentration to an area of lower concentration. The movement from a higher concentration to a lower concentration is called diffusion. In living systems, substances spontaneously diffuse from higher to lower areas of pressure, electrical charge, or concentration without the use of cellular energy. Figure 3.23 shows the process of diffusion in this subway situation.

The difference between higher and lower concentration areas is known as a gradient. Many examples of diffusion are seen throughout this text. Oxygen, carbon dioxide, alcohol, and vitamins move through a cell via diffusion. The kidneys work by regulating body levels of ions using diffusion principles. Simple cutting of an onion often makes us cry – not because we care about an onion's rights to live – but because sulfuric acid, an irritant, diffuses from the cut onion toward our eye membranes. Passive transport processes within cells can describe movement for many of the chemicals discussed in the previous chapter.

The mitochondria in our opening story use gradients to generate energy for a cell to use. Joules and Theta were fortunate to have more efficiently developed mitochondria to help their physiological functions. Movement of substances within the mitochondria

Passive transport

The movement of substances across cell membranes without the need of energy expenditure by the cell.

Equilibrium

The even level of dispersion of substances.

Concentration, higher and lower

The presence of a large amount of a specific substance in a solution or mixture is higher concentration. Any solution containing fewer dissolved particles is lower concentration.

Diffusion

The net movement of molecules from higher concentration to a lower concentration.

Gradient

The difference between higher and lower concentration areas.

Figure 3.23 Diffusion in a subway. Odor moves from a higher to a lower concentration in a subway car. Molecules bounce off of each other, moving farther and farther apart in diffusion.

will be discussed in greater detail in the next chapter, energetics. Next, we will look at a special case of passive diffusion of water across membranes, osmosis.

Osmosis: A Special Case of Diffusion

Because water is critical for life, it must be able to move freely into and out of cells – in other words, across membranes. Diffusion of water across a **selectively permeable membrane** – one that allows the transfer of only some substances – is termed osmosis. Osmosis occurs spontaneously, so it requires no cellular energy and is thus a special type of passive transport. It occurs only when water moves across a membrane. Most molecules within a cell cannot simply diffuse across a plasma membrane. If they could, their contents would readily spill out and a separation from the outside world would not be possible.

Osmosis

The process of diffusion of water through a semipermeable membrane that allows the transfer of only some substances.

While the integrity of the cell is critical, it is also critical that materials other than water move across the membrane. A unique property of water – its ability to dissolve other substances – makes this possible. The cell's cytoplasm is roughly 1% dissolved materials, and the right amount of dissolved material in the cell is required for proper cell functioning.

If a cell has a higher concentration of solute as compared with its surrounding environment it is hypertonic; if it has less solute, it is hypotonic. Osmosis is the mechanism by which the internal and external environments equalize. An example of what can happen when conditions are abnormal occurs when an athlete drinks a large amount of water in a short period of time following exercise and suffers from hypernatremia, or ion imbalance, which can be fatal (Figure 3.24).

Hypertonic

A cell having a higher concentration of solute as compared with its surrounding environment.

Hypotonic

A cell having a lower concentration of solute as compared with its surrounding environment.

The term **hyper**tonic can be remembered because "hyper" refers to a large amount of something, as in a hyperactive child who has too much energy. For example, if a cell with a concentration of 0.9% NaCl were placed in a beaker with a concentration of .01% NaCl, the cell would have the greater amount of solute. The cell, with more solute, has less water, and water would flow from the fluid outside into the cell. When that happens, the cell swells and could even lyse (break open) if too much water enters it.

Lyse

Breakdown of cell membrane.

Hypotonic solutions are those that have less solute dissolved than their external environment. The term **hypo**tonic can be remembered because "hypo" rhymes with H_2O, which implies that there is more plentiful water in a hypotonic situation. To illustrate,

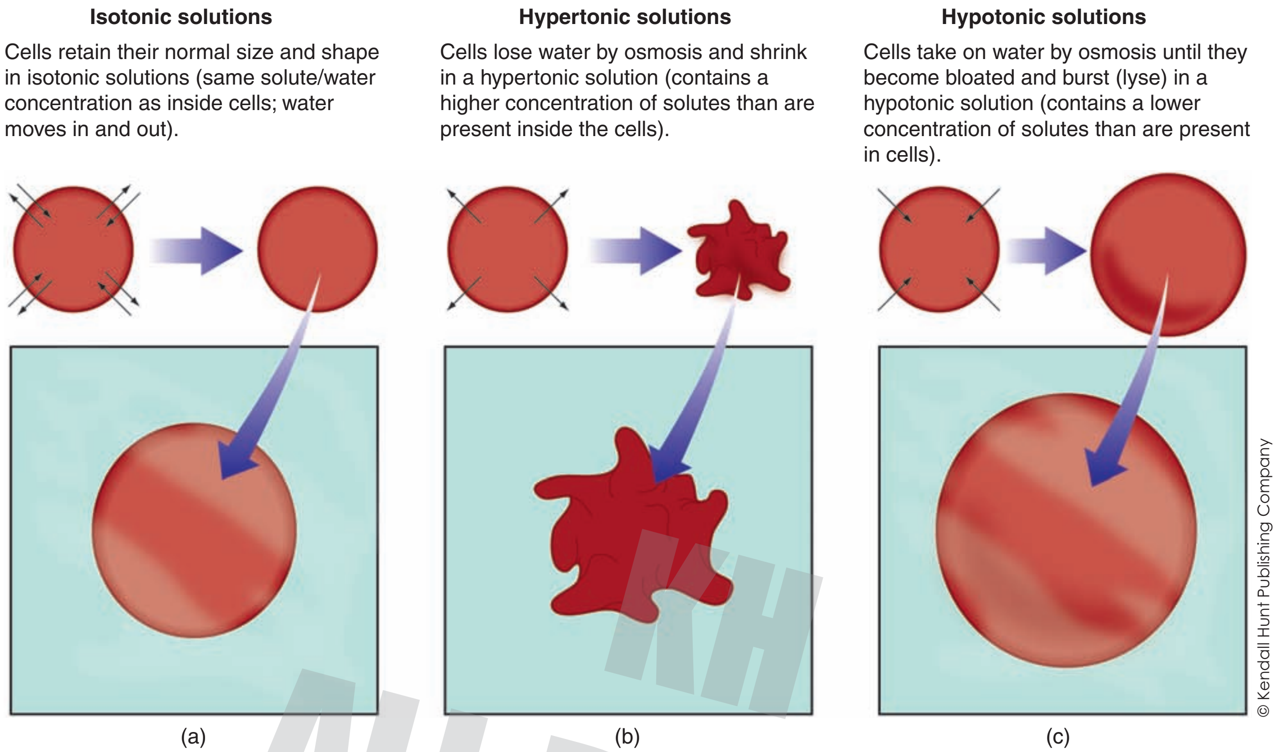

Figure 3.24 Red blood cells in hypotonic, hypertonic, and isotonic solutions. Red blood cells shrivel up in a hypertonic environment and blow up in a hypotonic environment. They are normal in an isotonic situation. Note the changes in a red blood cell's shape in each of the conditions.

when a cell with a concentration of 0.9% NaCl is placed in a beaker with a concentration of 10% NaCl, the cell has a lower amount of solute than the solution outside. The cell in this case is hypotonic, but the outside is hypertonic. Thus, water will flow out of the hypotonic cell along its concentration gradient. A good way to remember where water flows in cells is by the golden rule: "water follows solute."

Of course, no net movement of substances occurs if a cell has the same concentration of solute as its environment. It is then said to be isotonic (iso = the same as) to its outside. There is an even concentration of solute and water on either side of the plasma membrane. A cell might have a 0.9% concentration of NaCl both inside and outside of the cell. In this case, solute and water are both traveling in and out of the cell, but their net or overall movement is the same toward either side.

Isotonic
Even concentration of solute and water on either side of the plasma membrane.

Special Cases in Osmosis

Gradients drive the movement of solutes and water in each of the examples above. Single-celled organisms, such as the *Paramecium* described earlier in this chapter, live in hypotonic environments. Their surroundings contain a high concentration of water. Water is therefore always attempting to enter the *Paramecium* because it contains more dissolved solutes. This requires a contractile vacuole to act as a constant pump, moving the excess water out of the cell. This would make sense, because *Paramecium* is a freshwater protist, which needs dissolved solutes within its cell to survive.

Plants also use gradients to maintain their structure and stand upright. My grandmother often served older lettuce, as she was quite frugal. It wilted in the refrigerator, but after she placed the lettuce in a bowl of water, it perked up and looked as good as new. Lettuce cells were hypertonic to the outside, which was hypotonic to normal tap water. Water thus rushed into the cells of the lettuce leaves along their concentration gradient. Water entered water vacuoles within the plant cell, creating what is called turgor pressure, pressure exerted against the walls of a plant cell. Turgor is any pressure on a cell wall that gives the wall rigidity. My grandmother used the principles of osmosis to save money. When a plant cell is placed in a hypertonic environment, what do you predict will happen? It will lose water to its outside, causing it to shrink. Water's movement across a membrane not allowing solutes, as in our lettuce example, is shown in Figure 3.25.

Turgor pressure

The pressure exerted against the walls of a plant cell when water enters the water vacuoles of plant cell. Vacuole: Single membrane structures that hold materials in a cell.

Facilitated diffusion

A type of passive transport requiring a carrier protein.

Passive Transport with a Helper

Some substances require the help of carrier proteins to move across the plasma membrane. This final type of passive transport is called facilitated diffusion. Substances move along their concentration gradient through the channels of carrier proteins, which facilitate their movement. Sugars such as glucose, and amino acids, as components of proteins, both move into and out of cells through facilitated diffusion. Because they have charges on them they cannot cross the membrane on their own. Polar channels in carrier proteins enable these ions to be carried across the plasma membrane. Facilitated diffusion requires no cellular energy and it occurs spontaneously, moving from a higher to lower concentration.

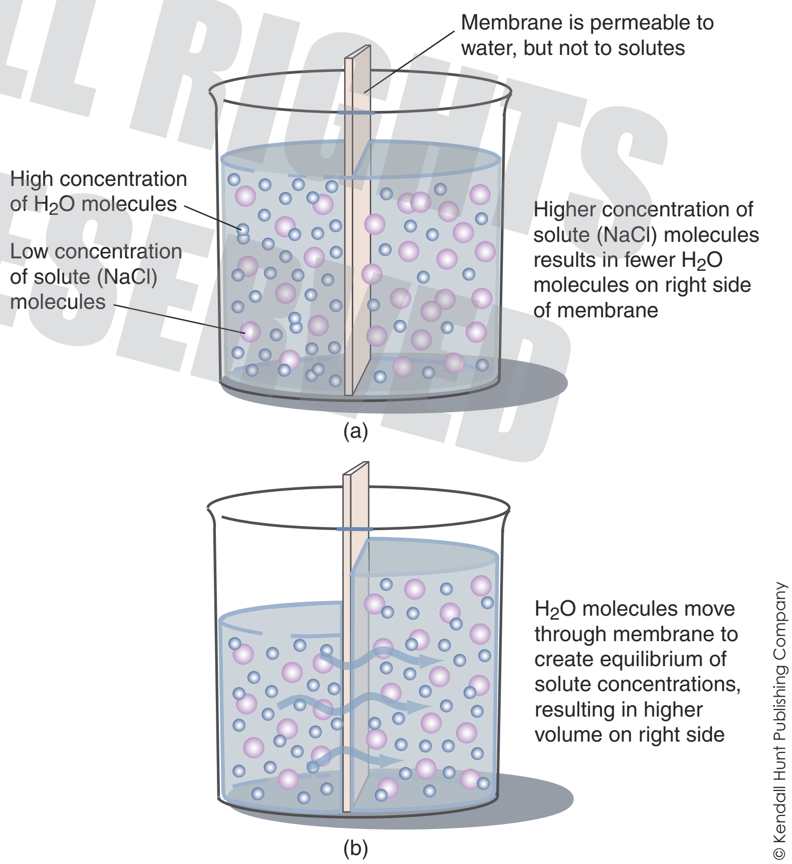

Figure 3.25 Water moves across the membrane between two sides of the beaker but does not permit the movement of dissolved substances. This leads to a column of water rising as water follows solute into the right side of the beaker. Lettuce, in our example, has increased turgor pressure as water rushes into its cells.

Our story discussed mitochondria, which have much movement of ions within its inner membranes to make ATP energy. Next we will look at how ATP energy generated by mitochondria drives another form of movement: active transport.

Active Transport

Some forms of movement occur with the addition of energy to drive its actions. Active transport is the movement of substances against a concentration gradient, from a lower concentration to a higher concentration, which requires cellular energy. Active transport does not occur spontaneously; it requires ATP energy to overcome the nonspontaneous movement of materials against a concentration gradient. Consider our subway example: Would it not be strange if all of the smell molecules aggregated toward the armpit of an unsuspecting person on the subway, making him or her smell terribly? Could smell molecules throughout the subway car attack this person? It cannot happen unless there is an active transport mechanism at work.

Active transport

Is the movement of substances against a concentration gradient, from a lower concentration to a higher concentration, which requires cellular energy.

In order for cells to carry out some processes, they must use active transport. For example, the sodium–potassium pump is an integral protein that uses ATP energy to move sodium ions (Na^+) out of the cell and bring potassium ions (K^+) into the cell. Keeping the right concentrations of Na^+ and K^+ is vital in nerve and muscle activity.

Sodium–potassium pump

An integral protein that uses ATP energy to move sodium ions out of the cell and bring potassium ions into the cell.

A concentration gradient forms as a result of three Na^+ pumped out of the cell for every two K^+ pumped into the cell. This specific movement results in an electrical and concentration gradient across the membrane. More sodium winds up outside of the cell and more potassium inside. The environment outside the cell becomes more positive than inside it because there are more positive ions being pumped out. Potential or stored energy develops and drives many cellular activities much as a dam on a river stores energy that is converted to electrical power for our use. Figure 3.26 shows the workings of the sodium–potassium pump.

Secondary active transport is the movement of substances using stored energy. The sodium–potassium pump creates a store of electrical and potential energy for later use by cell processes. Instant energy for moving one's arm or riding a bicycle is obtained through secondary active transport by using stored ATP. Let's give a look in the next section to the active movement of bulk materials in and out of the cell.

Secondary active transport

The movement of substances using stored energy.

Bulk Transport: A Bigger Moving Van

At times, cells as a city require transport of larger materials – sometimes, whole organisms – to carry out their life functions. Bulk transport is the movement of large amounts of material across the plasma membrane. It is a form of active transport obtaining energy from ATP. Movement of single ions or molecules is often not enough for the many cell reactions occurring at any one time. Cell activities often require removal or inputs of large resources.

Bulk transport

Is the movement of large amounts of material across the plasma membrane.

The moving van of the cell is the vesicle, containing the bulk materials. Bulk transport can occur by moving materials into the cell (called endocytosis) or by moving material out of a cell (exocytosis). (*Endo*- sounds like "in" and *exo*- sounds like "exit," which should help you recall the terms.) There are three types of endocytosis: phagocytosis, pinocytosis, and receptor-mediated endocytosis.

Endocytosis

The process of moving materials into the cell.

Exocytosis

The process of moving materials outside the cell.

Phagocytosis is defined as the movement of solid particles into a cell. It is accomplished by a cell's cytoplasm projecting around the material to be dissolved. This action appears much like a blob, engulfing its prey. The substance may be a whole organism or a particle of organic matter. Immune cells, particularly macrophages, a special kind of white blood cell, attack foreign invaders by phagocytosis. Once the material is

Phagocytosis

The movement of solid particles into a cell.

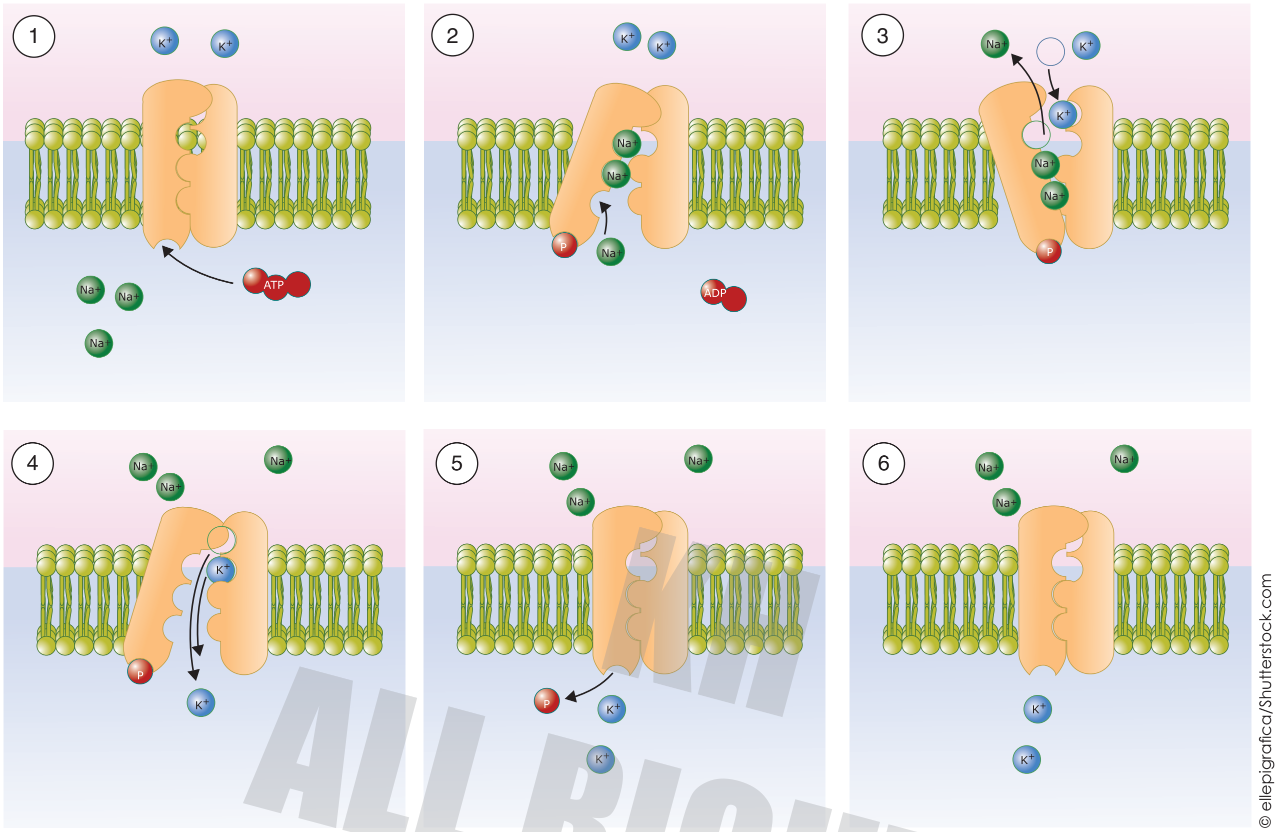

Figure 3.26 The workings of the sodium–potassium pump. With each turn, the pump moves three sodium ions out of its cell and two potassium ions into its cell. A gradient is set up with more sodium ions outside than inside a cell. The inside of the cell becomes relatively more negative than the outside because more positive charges are pumped to the outside of the cell.

fully engulfed through this process, lysosomes fuse with the newly formed vesicle containing the material. Lysosome's hydrolytic enzymes digest the particle for use by a cell or release it as a waste product.

Cells also move large amounts of liquid, along with their dissolved solutes, into their cytoplasm through pinocytosis. Cell drinking or pinocytosis requires a furrow, or invagination, in the plasma membrane of a cell to input liquids. Many animal cells obtain their nutrients through pinocytosis, with large human egg cells developing multiple furrows to obtain nutrients from the surrounding cells.

A form of endocytosis that requires a specific binding of a receptor protein to cell membrane is known as receptor-mediated endocytosis. In this case, bulk materials move into a cell by docking with a specifically shaped receptor. The receptor is an integral protein jutting out of a plasma membrane. It has a specific shape onto which a substance matching its shape may bind. A signal stimulated by the joining of receptor to substance starts to bring the plasma membrane inward. The membrane forms a vesicle filled with both the substance bound to the receptor and the materials dissolved, as the membrane moves inward. Hormones, nutrients, and neurotransmitters, such as acetylcholine (described in Chapter 1), move in and out of a cell through this process.

Because receptors are proteins, they are genetically determined. For example, in cases of hyperlipidemia, high amounts of cholesterol build up in the blood. Receptors that dock with vesicles carrying cholesterol are either malformed or available in

Pinocytosis

The mechanism by which cells ingest extracellular fluid and its contents.

Invagination

The process of being folded back on itself to form a pouch (not given in bold in text).

Receptor-mediated endocytosis

A form of endocytosis that requires a specific binding of a receptor protein to cell membrane.

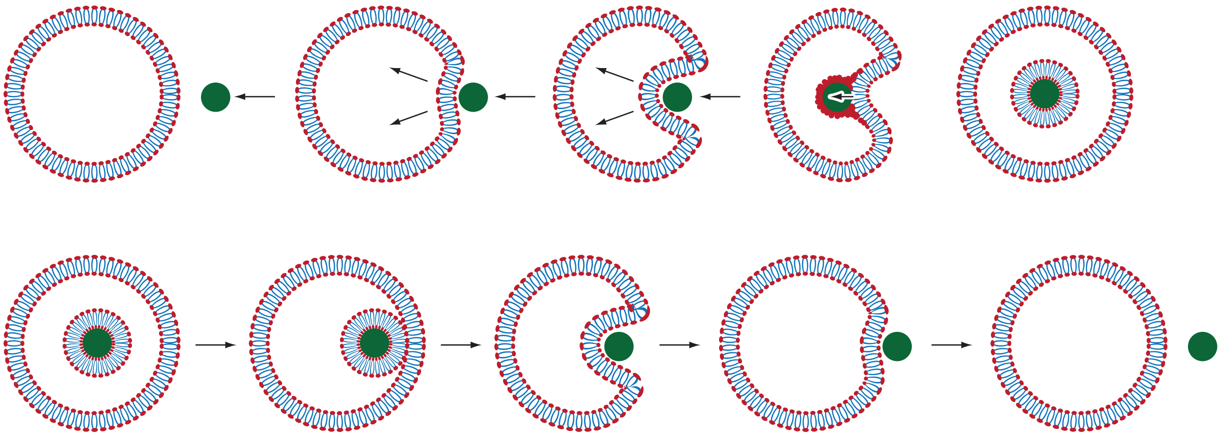

Figure 3.27 Endocytosis and exocytosis.

insufficient amounts in hyperlipidemia. Lipids cannot be removed from the blood as easily, reducing rates of receptor-mediated endocytosis and leading to buildup of fats in the blood. It is a dangerous disease due to its close link with heart attacks and stroke. Many other diseases are associated with improperly formed receptors, including diabetes, depression, and susceptibility to viruses.

All bulk movement out of a cell is accomplished by exocytosis. Any material to be exported – wastes, hormones, mucous or enzymes – is removed from a cell by exocytosis. Exocytosis removes either waste products or materials for export from the cell. Vesicles containing these materials fuse with the plasma membrane and are expelled. Figure 3.27 shows the types of bulk transport.

All of the forms of bulk transport are used by mitochondria described in our opening story. For a mitochondrion to function, much like any other organelle, it communicates with the nucleus, cell membrane, and other cell parts to perform its role in helping the cell to function. Joules and Theta probably did not realize the complexity of cell movement within their mitochondria that contribute to its survival. Perhaps if they had, they would have accepted their friend Sally. Knowing that mitochondrial DNA is not the only contributor to an individual cell's survival would have opened their eyes to the many unknowns in making each of us unique. Cell biology might have made a difference in the outcome of our story and in the friendship of Joules, Theta, and Sally.

IT'S ALL ABOUT EVE: EVERYONE HAS THE SAME MOTHER IN OUR HISTORY.

Our story opens with the importance of ancestral mitochondrial DNA in social organization. However, evidence shows that all humans have the same maternal mitochondria, derived from the same ancestral mother.

A group of genetic researchers published a study in the journal Nature revealing a maternal ancestor to all living humans called "mitochondrial Eve." Researchers concluded that every human on Earth now could trace lineage back to this single common female ancestor who lived around 200,000 years ago.

Mitochondrial DNA was taken from 147 people across continents and ethnic groups. It was determined that people alive today have lineage on one of two branches in the human family tree. One branch consists of African lineage only and the other of all other groups including African. The scientists concluded that Africa is the place where this woman lived. Note that this maternal ancestor was not the first woman, but her descendants survive to present day while other women of her time had female descendants with no children, halting the passing on mitochondrial DNA.

Thus, Joules, Theta, and Sally were of one lineage, bound by an ancestor long ago. While society broke them apart, their biology had more in common than Joules would know or care to admit. Their commonalities should have held them together, with the humanness of a shared heritage. Perhaps their ancestor is one of us now . . .

Summary

Chemistry is the language of structure and movement within living systems. Physical and chemical principles determine the behavior of cell structures. Developments in microscopy led to the discovery of the detailed workings of cells. While most organelles evolved through invaginations of membranes, mitochondria and eukaryotes developed by becoming absorbed into larger cells. Together, organelle interactions with one another and the outside environment comprise a living organism. The fluid mosaic model shows how cells transport materials across their many membranes. Transport systems accomplish varied goals from moving small particles directly through cells to moving materials in bulk. All of the needs of cells are accomplished by organelles communicating through use of the different transport systems. Our story showed that cell parts not only dictate only life processes, but influence human health and the social structure of our society.

CHECK OUT

Summary: Key Points

- Cell biology affects our lives in many ways, from diseases such as lysosome storage disorders to the way society is structured based on human differences.
- Organelles have specific roles within cells, communicating with each other and the outside environment through membranes.
- The endosymbiotic theory explains the origin of mitochondria and chloroplasts in eukaryotic cells based on chemical and biological evidence.
- The development of microscopy led to the discovery of cells and cell parts.
- The plasma membrane has a unique structure that enables transport across a cell.
- Cells of the five kingdoms diverge based on just a few key differences.
- Passive and active transport mechanisms are used to move materials within a cell.
- Different chemicals use transport mechanisms differently to move across a cell.

KEY TERMS

active transport
aerobic
bulk transport
cell respiration
centriole
chloroplast
chromatin
chromosome
chromoplast
cilia
compartmentalization
compound light microscope
concentration, higher and lower
cristae
cytoplasm
desmosome
diffraction
diffusion
endocytosis
endoplasmic reticulum (ER)
endosymbionts
endosymbiotic theory
equilibrium
exocytosis
facilitated diffusion
flagella
fluid mosaic model
gap (communicating) junction
golgi apparatus
gradient
hypertonic
hypotonic
integral protein (transmembrane or carrier protein)
intermediate fiber
intracellular digestion
intracellular transport
invagination
isotonic
leucoplast
lyse
lysosome
lysosome storage disease
magnification
microfilament
micrometer
microtubule
mitochondria
nanometer
nuclear envelop
nucleoli
nucleus
organelle (subcellular structure)
osmosis
oxygen revolution
passive transport
peripheral protein
phagocytosis
photosynthesis
pinocytosis
plasma (cell) membrane
plasmolysis
plastid
receptor
receptor-mediated endocytosis
recognition protein
resolution
ribosome
scanning electron microscope (SEM)
secondary active transport
selectively permeable
sodium–potassium pump
stoma
thylakoid membrane
tight junction
transmission electron microscope (TEM)
turgor pressure
vacuole

Multiple Choice Questions

1. How might a chloroplast disease, preventing its key processes, affect human society?
   a. There would be no more food.
   b. There would be no more light.
   c. There would be no more water.
   d. There would be no more carbon dioxide.

2. If a plant cell absorbs water and becomes stiff, it becomes __________ through the process of __________.
   a. crenated; passive transport
   b. turgid; osmosis
   c. rigid; active transport
   d. reactive; facilitated diffusion

3. Which sentence BEST describes a ribosome?
   a. It is a large organelle that makes protein.
   b. It is a small organelle that makes protein.
   c. It is a large organelle that breaks down protein.
   d. It is a small organelle that breaks down protein.

4. Which type of microscope can best view the cristae of a mitochondrion?
   a. compound light microscope
   b. phase contrast microscope
   c. scanning electron microscope
   d. transmission electron microscope

5. Which term best describes the plasma membrane?
   a. static
   b. dynamic
   c. organized
   d. rigid

6. Which term best differentiates between active transport and passive transport?
   a. polarity
   b. facilitation
   c. concentration
   d. energy

7. Which is NOT a passive transport mechanism across a plant cell?
   a. turgor pressure
   b. diffusion
   c. osmosis
   d. receptor-mediated endocytosis

8. When a cell builds a new Golgi apparatus, new materials need to be brought into the cell, sometimes against a concentration gradient. Which process best accomplishes the task of building a new Golgi apparatus?
   a. diffusion
   b. osmosis
   c. exocytosis
   d. active transport

9. In question #8 above, which chemical drives the process for the correct answer?
   a. sodium
   b. water
   c. ATP
   d. adenine

10. An experiment places a skin cell within a petri dish containing pure, distilled water. Predict what will happen to the skin cell within minutes:
   a. The skin cell will shrink as water leaves the cell.
   b. The skin cell will lyse as water leaves the cell.
   c. The skin cell will shrink as water enters the cell.
   d. The skin cell will lyse as water enters the cell.

Short Answers

1. Describe how senescence is linked to lysosomes. Explain how lysosomes are both linked to human diseases and to our proper functioning. Give an example of each.

2. Define the following terms: passive transport, active transport, and receptor-mediated endocytosis. List one way each of the terms differs from the others.

3. Compare the two types of electron microscopes, explaining how their images are similar and how they are different. Use a drawing to make the distinctions clear. Show your art work. Which was more important in discovering subcellular structure?

4. There are several ways chemicals move within cells. At times they use passive transport and at times they use active transport. List the types of passive transport and explain how each works. Be sure to include the following terms in your explanation: gradient, concentration, and ATP energy?

5. For question #4 above, list and draw an example of an active transport mechanism within a cell. Include in the picture the electron arrangement around the atoms.

6. Name two differences and two similarities between cells found in the matched kingdoms:

a. fungi–protist
b. animal–plant
c. plant–protist
d. bacteria–animal

7. ATP plays a major role in life's processes. How does ATP energy function in secondary active transport processes? Explain how the sodium–potassium pump plays a role in secondary active transport.

8. Draw the fluid mosaic model of the cell membrane. Describe how and why a charged molecule such as sugar that needed by every cell enters through the fluid mosaic.

9. Explain the differences between passive and active transport. Explain the difference using the following terms: ATP, spontaneous, gradient, concentration, ions.

10. A battle between an amoeba and a single-celled protist, *chilomonas* ensues. The amoeba wins, but the large piece of *chilomonas* is too big to pass through the plasma membrane of the *amoeba* to eat. Describe the process by which the amoeba absorbs and digests the *chilomonas*.

Biology and Society Corner: Discussion Questions

1. Many scientists argue that our most pressing resource crisis is not food shortage or climate change, but water scarcity. How is water important for a cell? Predict how the role of a limited water supply will affect society. Explain how the water crisis is already impacting policy changes, the economy and overall human impacts on the environment.

2. How would van Leeuwenhoek be surprised by discoveries since his viewing of cells? What role do you think microscopy will play in future scientific developments? How did microscopy affect society in the 20th century? Use either the scanning electron microscope or transmission electron microscope to frame your thesis.
3. If a person is stranded on a desert island, without freshwater, what are the dangers of drinking sea water. Explain the transport mechanism at work, which leads to problems for a human cell in contact with seawater.
4. Mitochondrial diseases are attributed to human health problems, from sweating and epilepsy to diabetes and heart disease. Do you support biotechnology research to help people with these diseases? Do you support its use in potentially making "better" mitochondria to help people live better lives, as seen in our story. What restrictions would you place, if any, on such developments?
5. Plasma membranes are delicate and can weaken in some cases causing human health disorders. Research the effects of plasma membrane problems on the health of humans and animals. Choose one of the organelles discussed in this chapter. Describe what happens to the organelle and human or animal health as a result of the delicate nature of plasma membranes.

Figure – Concept Map of Chapter 3 Big Ideas