Introduction to the cell cell history cell structures and functions

CK-12 Foundation

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Cell structure and function dec 16

1.1 Lesson 3.1: Introduction to Cells

Lesson Objectives

- Identify the scientists that first observed cells.
- Outline the importance of microscopes in the discovery of cells.
- Summarize what the cell theory proposes.
- Identify the limitations on cell size.
- Identify the four parts common to all cells.
- Compare prokaryotic and eukaryotic cells.

Introduction

Knowing the make up of cells and how cells work is necessary to all of the biological sciences. Learning about the similarities and differences between cell types is particularly important to the fields of cell biology and molecular biology. The importance of the similarities and differences between cell types is a unifying theme in biology. They allow the principles learned from studying one cell type to be applied when learning about other cell types. For example, learning about how single-celled animals or bacteria work can help us understand more about how human cells work. Research in cell biology is closely linked to genetics, biochemistry, molecular biology, and developmental biology.

Discovery of Cells

A **cell** is the smallest unit that can carry out the processes of life. It is the basic unit of all living things, and all organisms are made up of one or more cells. In addition to having the same basic structure, all cells carry out similar life processes. These include transport of materials, obtaining and using energy, waste disposal, replication, and responding to their environment.

If you look at living organisms under a microscope you will see they are made up of cells. The word cell was first used by Robert Hooke, a British biologist and early microscopist. Hooke looked at thin slices of cork under a microscope. The structure he saw looked like a honeycomb as it was made up of many tiny units. Hooke's drawing is shown in **Figure** 1.1. In 1665 Hooke published his book *Micrographia,* in which he wrote:

> ... I could exceedingly plainly perceive it to be all perforated and porous, much like a Honey-comb, but that the pores of it were not regular.... these pores, or cells, ... were indeed the first *microscopical* pores I ever saw, and perhaps, that were ever seen, for I had not met with any Writer or Person, that had made any mention of them before this...

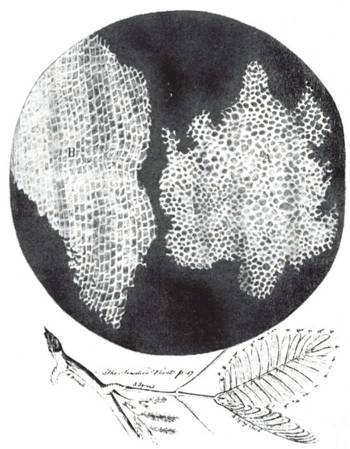

Figure 1.1: Drawing of the structure of cork from as it appeared under the microscope to Robert Hooke. The first scientific use of the word appears in this book.

During the 1670s, the Dutch tradesman Antony van Leeuwenhoek, shown in **Figure** 1.2, used microscopes to observe many microbes and body cells. Leeuwenhoek developed an interest in microscopy and ground his own lenses to make simple microscopes. Compound microscopes, which are microscopes that use more than one lens, had been invented around 1595. Several people, including Robert Hooke, had built compound microscopes and were making important discoveries with them during Leeuwenhoek's time. These compound microscopes were very similar to the microscopes in use today. However, Leeuwenhoek was so good at making lenses that his simple microscopes were able to magnify much more clearly than the compound microscopes of his day. His microscope's increased ability to magnify over 200 times is comparable to a modern compound light microscope.

Leeuwenhoek was also very curious, and he took great care in writing detailed reports of what he saw under his microscope. He was the first person to report observations of many microscopic organisms. Some of his discoveries included tiny animals such as ciliates, foraminifera, roundworms, and rotifers, shown in **Figure** 1.3. He discovered blood cells and was the first person to see living sperm cells. In 1683, Leeuwenhoek wrote to the Royal Society of London about his observations on the plaque between his own teeth, "a little white matter, which is as thick as if 'twere batter." He called the creatures he saw in the plaque *animacules*, or tiny animals. This report was among the first observations on living bacteria ever recorded.

Figure 1.2: Antony van Leeuwenhoek (1632-1723). His carefully crafted microscopes and insightful observations of microbes led to the title the "Father of Microscopy."

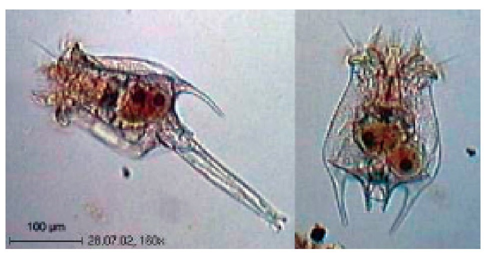

Figure 1.3: Rotifers, similar to the type that Leeuwenhoek saw under his microscope.

Microscopes

Hooke's and Leeuwenhoek's studies and observations filled people with wonder because their studies were of life forms that were everywhere, but too small to see with the naked eye. Just think how amazed you would be if you were to read about the first accounts of a newly discovered microorganism from the moon or Mars. Your first thought might be "Things can live there?!" which was probably the first thought of the people who read Hooke's and Leeuwenhoek's accounts. The microscope literally opened up an amazing new dimension in the natural sciences, and became a critical tool in the progress of biology.

Magnifying glasses had been in use since the 1300s, but the use of lenses to see very tiny objects was a slowly-developing technology. The magnification power of early microscopes was very limited by the glass quality used in the lenses and the amount of light reflected off the object. These early light microscopes had poor resolution and a magnification power of about 10 times. Compare this to the over 200 times magnification that Leeuwenhoek was able to achieve by carefully grinding his own lenses. However, in time the quality of microscopes was much improved with better lighting and resolution. It was through the use of light microscopes that the first discoveries about the cell and the cell theory (1839) were developed.

However, by the end of the 19^{th} century, light microscopes had begun to hit resolution limits. **Resolution** is a measure of the clarity of an image; it is the minimum distance that two points can be separated by and still be distinguished as two separate points. Because light beams have a physical size, it is difficult to see an object that is about the same size as the wavelength of light. Objects smaller than about 0.2 micrometers appear fuzzy, and objects below that size just cannot be seen. Light microscopes were still useful, but most of the organelles and tiny cell structures discussed in later lessons were invisible to the light microscope.

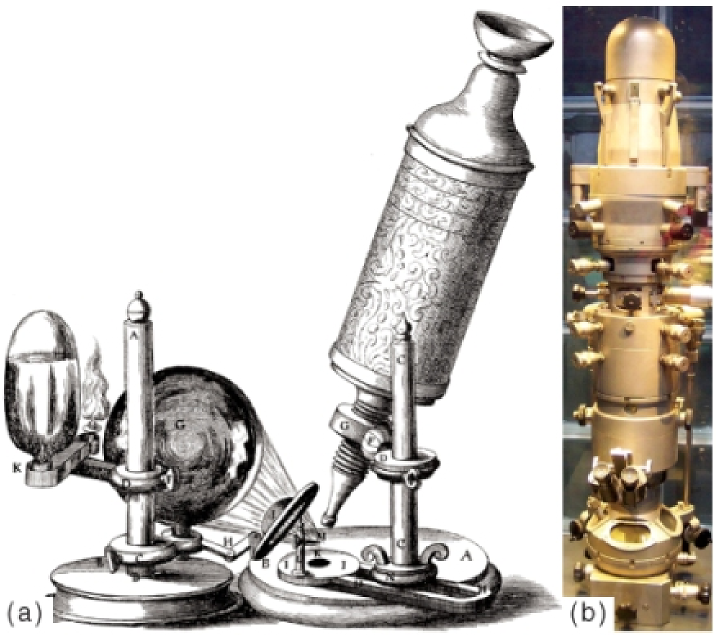

Figure 1.4: Left to right: (a) Hookes light microscope (b) Modern electron microscope.

In the 1950s, a new system was developed that could use a beam of electrons to resolve very tiny dimensions at the molecular level. Electron microscopes, one of which is shown in **Figure** 1.4, have been used to produce images of molecules and atoms. They have been used to visualize the tiny sub-cellular structures that were invisible to light microscopes. Many of the discoveries made about the cell since the 1950s have been made with electron microscopes.

The Cell Theory

Later, biologists found cells everywhere. Biologists in the early part of the 19th century suggested that all living things were made of cells, but the role of cells as the primary building block of life was not discovered until 1839 when two German scientists, Theodor Schwann, a zoologist, and Matthias Jakob Schleiden, a botanist, suggested that cells were the basic unit of all living things. Later, in 1858, the German doctor Rudolf Virchow observed that cells divide to produce more cells. He proposed that all cells arise only from other cells. The collective observations of all three scientists form the *cell theory*. The modern cell theory states that:

- All organisms are made up of one or more cells.
- All the life functions of an organism occur within cells.
- All cells come from preexisting cells.

As with any theory, the cell theory is based on observations that over many years upheld the basic conclusions of Schwann's paper written in 1839. However, one of Schwann's original conclusions stated that cells formed in a similar way to crystals. This observation, which refers to *spontaneous generation* of life, was discounted when Virchow proposed that all cells arise only from other cells. The cell theory has withstood intense examination of cells by modern powerful microscopes and other instruments. Scientists use new techniques and equipment to look into cells to discover additional explanations for how they work.

Diversity of Cells

Different cells within a single organism can come in a variety of sizes and shapes. They may not be very big, but their shapes can be very different from each other. However, these cells all have common abilities, such as getting and using food energy, responding to the external environment, and reproducing. A cell's shape determines its function.

Cell Size

If cells have such an important job, why are they so small? And why are there no organisms with huge cells? The answers to these questions lie in a cell's need for fast, easy food. The need to be able to pass nutrients and gases into and out of the cell sets a limit on how big cells can be. The larger a cell gets, the more difficult it is for nutrients and gases to move in and out of the cell.

As a cell grows, its volume increases more quickly than its surface area. If a cell was to get very large, the small surface area would not allow enough nutrients to enter the cell quickly enough for the cell's needs. This idea is explained in **Figure** 1.5. However, large cells have a way of dealing with some size challenges. Big cells, such as some white blood cells, often grow more nuclei so that they can supply enough proteins and RNA for the cell's needs. Large, metabolically active cells often have lots of folds in their cell surface membrane. These folds increase the surface area available for transport into or out of the cell. Such cell types are found lining your small intestine, where they absorb nutrients from your food through little folds called *microvilli*.

Scale of Measurements

1 centimeter (cm) = 10 millimeters (mm) = 10^{-2} meters (m)

1 mm = 1000 micrometers (µm) = 10^{-3} m

1 µm = 1000 nanometers (nm) = 10^{-6} m

1 nm = 10^{-3} µm

Imagine cells as little cube blocks. A small cube cell is one unit in length.

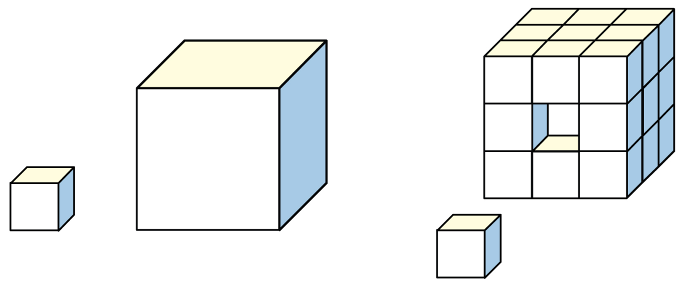

Figure 1.5: A small cell (left), has a larger surface-area to volume ratio than a bigger cell (center). The greater the surface-area to volume ratio of a cell, the easier it is for the cell to get rid of wastes and take in essential materials such as oxygen and nutrients.

The total surface area of this cell is calculated by the equation:

height $\times$ width $\times$ number of sides $\times$ number of boxes

$1 \times 1 \times 6 \times 1 = 6$

The volume of the cell is calculated:

height x width x length x number of boxes

$1 \times 1 \times 1 \times 1 = 1$

The surface-area to volume ratio is:

area $\div$ volume

$6 \div 1{=}6$

A larger cell that is 3 units in length would have a total surface area of

$3 \times 3 \times 6 \times 1 = 54$

and a volume of:

$3 \times 3 \times 3 \times 1 = 27$

The surface-area to volume ratio of the large cell is:

$54 \div 27{=}2$

Now, replace the three unit cell with enough one unit cells to equal the volume of the single three unit cell. This can be done with 27 one unit cells. Find the total surface area of the 27 cells:

$1 \times 1 \times 6 \times 27 = 162$ units

The total volume of the block of 27 cells is:

$1 \times 1 \times 1 \times 27 = 27$

The surface-area to volume ratio of the 27 cells is:

$162 \div 27{=}6$

An increased surface area to volume ratio means increased exposure to the environment. This means that nutrients and gases can move in and out of a small cell more easily than in and out of a larger cell.

The smallest prokaryotic cell currently known has a diameter of only 400 nm. Eukaryotic cells normally range between 1– 100 µm in diameter.

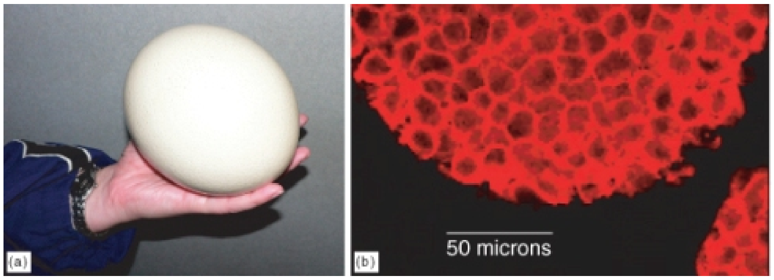

Figure 1.6: Ostrich eggs (a) can weigh as much as 1.5 kg, and be 13 cm in diameter, whereas each of the mouse cells (b) shown at right are each about 10 m in diameter, much smaller than the period at the end of this sentence.

The cells you have learned about so far are tinier than the period at the end of this sentence, so they are normally measured on a very tiny scale. Most cells are between 1 and 100 µm in diameter. The mouse cells in **Figure** 1.6 are about 10 µm in diameter. One exception however, is eggs. Eggs contain the largest known single cell, and the ostrich egg is the largest of them all. The ostrich egg in **Figure** 1.6 is over 10,000 times larger than the mouse cell.

Cell Shape

The variety of cell shapes seen in prokaryotes and eukaryotes reflects the functions that each cell has. Each cell type has evolved a shape that best helps it survive and do its job. For example, the nerve cell in **Figure** 1.7 has long, thin extensions that reach out to other nerve cells. The extensions help the nerve cell pass chemical and electrical messages quickly through the body. The spikes on the pollen grain help it stick to a pollinating insect or animal so that it can be transferred to and pollinate another flower. The long whip-like flagella (tails) of the algae *Chlamydomonas* help it swim in water.

Parts of a Cell

There are many different types of cells, but all cells have a few things in common. These are:

- a cell or plasma membrane
- cytoplasm
- ribosomes for protein synthesis
- DNA (genetic information)

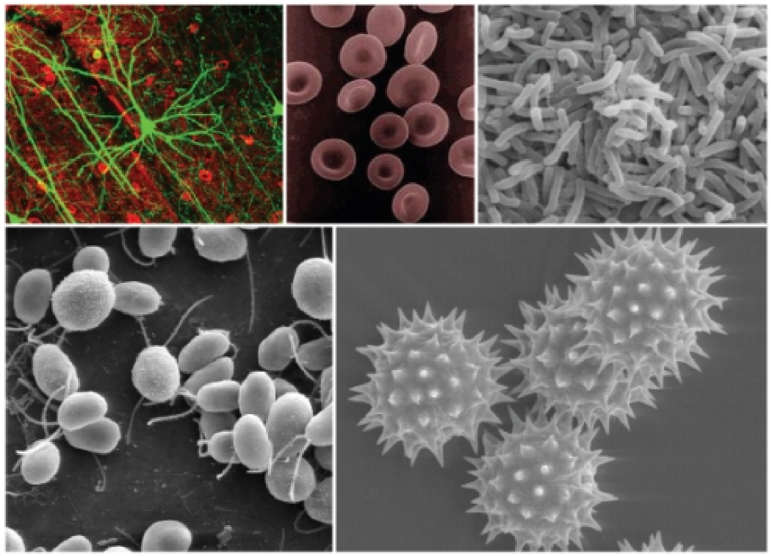

Figure 1.7: Cells come in very different shapes. Left to right, top row: Long, thin nerve cells; biconcave red blood cells; curved-rod shaped bacteria. Left to right, bottom row: oval, flagellated algae and round, spiky pollen grains are just a sample of the many shapes.

The **cell membrane** is the physical boundary between the inside of the cell (intracellular) and its outside environment (extracellular). It acts almost like the "skin" of the cell. **Cytoplasm** is the general term for all of the material inside the cell. Cytoplasm is made up of *cytosol*, a watery fluid that contains dissolved particles and organelles. **Organelles** are structures that carry out specific functions inside the cell. **Ribosomes** are the organelles on which proteins are made. Ribosomes are found throughout the cytosol of the cell. All cells also have DNA. DNA contains the genetic information needed for building structures such as proteins and RNA molecules in the cell.

Two Types of Cells

There are two cell types: prokaryotes and eukaryotes. Prokaryotic cells are usually single-celled and smaller than eukaryotic cells. Eukaryotic cells are usually found in multicellular organisms, but there are some single-celled eukaryotes.

Prokaryotic Cells

The bacterium in **Figure** 1.8 is a prokaryote. **Prokaryotes** are organisms that do not have a cell nucleus nor any organelles that are surrounded by a membrane. Some cell biologists consider the term "organelle" to describe membrane-bound structures only, whereas other cell biologists define organelles as discrete structures that have a specialized function. Prokaryotes have ribosomes, which are not surrounded by a membrane but do have a specialized function, and could therefore be considered organelles. Most of the metabolic functions carried out by a prokaryote take place in the plasma membrane.

Most prokaryotes are unicellular and have a cell wall that adds structural support and acts as a barrier

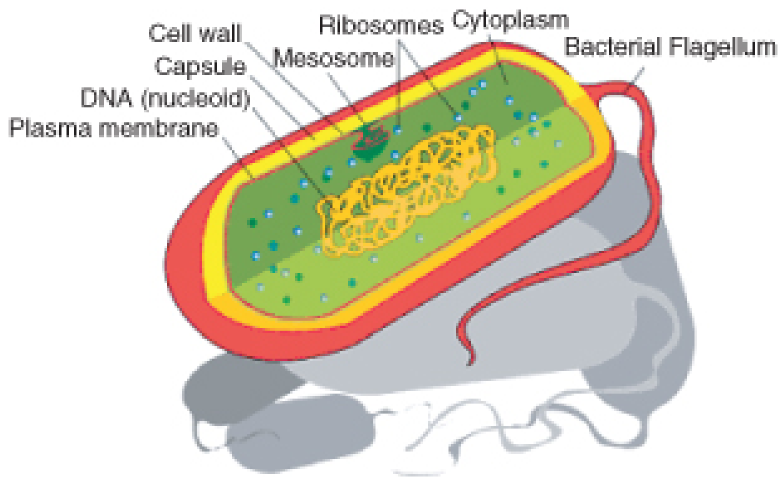

Figure 1.8: Diagram of a typical prokaryotic cell. Among other things, prokaryotic cells have a plasma membrane, cytoplasm, ribosomes, and DNA. Prokaryotes do not have membrane-bound organelles or a cell nucleus.

against outside forces. Some prokaryotes have an extra layer outside their cell wall called a capsule, which helps them stick to surfaces or to each other. Prokaryotic DNA usually forms a circular molecule and is found in the cell's cytoplasm along with ribosomes. Prokaryotic cells are very small; most are between 1–10 μm in diameter. They are found living in almost every environment on Earth. Biologists believe that prokaryotes were the first type of cells on Earth and that they are the most common organisms on Earth today.

Eukaryotic Cells

A **eukaryote** is an organism whose cells are organized into complex structures by internal membranes and a cytoskeleton, as shown in **Figure** 1.12. The most characteristic membrane-bound structure of eukaryotes is the nucleus. This feature gives them their name, which comes from Greek and means "true nucleus." The **nucleus** is the membrane-enclosed organelle that contains DNA. Eukaryotic DNA is organized in one or more linear molecules, called chromosomes. Some eukaryotes are single-celled, but many are multicellular.

In addition to having a plasma membrane, cytoplasm, a nucleus and ribosomes, eukaryotic cells also contain membrane-bound organelles. Each organelle in a eukaryote has a distinct function. Because of their complex level of organization, eukaryotic cells can carry out many more functions than prokaryotic cells. The main differences between prokaryotic and eukaryotic cells are shown in **Figure** 1.11 and listed in **Table 1**. Eukaryotic cells may or may not have a cell wall. Plant cells generally have cell walls, while animal cells do not.

Eukaryotic cells are about 10 times the size of a typical prokaryote; they range between 10 and 100 μm in diameter while prokaryotes range between 1 and 10 μm in diameter, as shown in **Figure** 1.10. Scientists believe that eukaryotes developed about 1.6 – 2.1 billion years ago. The earliest fossils of multicellular organisms that have been found are 1.2 billion years old.

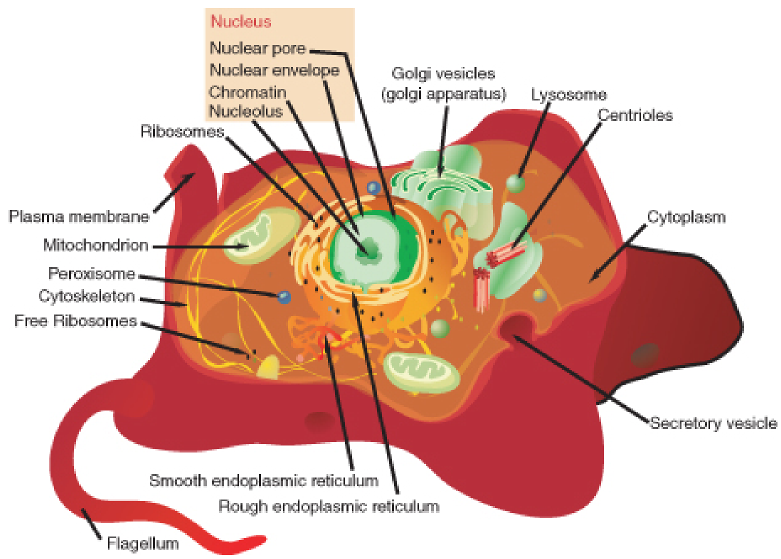

Figure 1.9: A eukaryotic cell, represented here by a model animal cell is much more complex than a prokaryotic cell. Eukaryotic cells contain many organelles that do specific jobs. No single eukaryotic cell has all the organelles shown here, and this model shows all eukaryotic organelles.

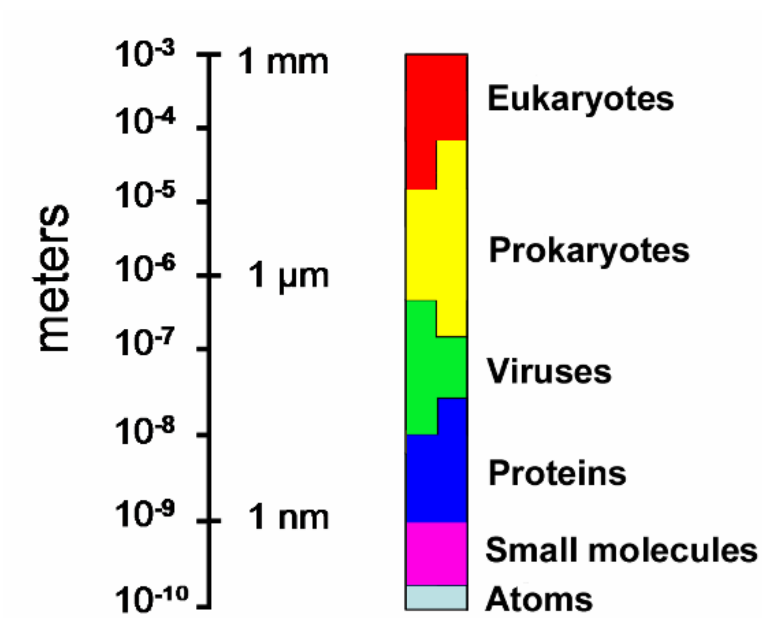

Figure 1.10: The relative scale of prokaryotic and eukaryotic cells. See how eukaryotic cells are generally 10 to 100 times larger than prokaryotic cells.

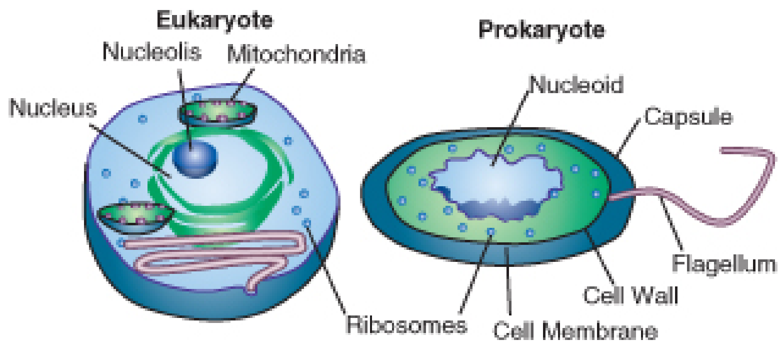

Figure 1.11: The main differences between prokaryotic and eukaryotic cells. Eukaryotic cells have membrane bound organelles while prokaryotic cells do not.

Table 1.1: Structural Differences Between Prokaryotic Cells and Eukaryotic Cells

Presence of	Prokaryote	Eukaryote
Plasma membrane	yes	yes
Genetic material (DNA)	yes	yes
Cytoplasm	yes	yes
Ribosomes	yes	yes
Nucleus	no	yes
Nucleolus	no	yes
Mitochondria	no	yes
Other membrane-bound organelles	no	yes
Cell wall	yes	some (not around animal cells)
Capsule	yes	no
Average diameter	0.4 to 10 µm	1 to 100 µm

Lesson Summary

- Robert Hooke first saw and named cells. Antony van Leeuwenhoek was the first person to see living cells.
- Before the development of microscopes, the existence of cellular life was unknown. The development of light microscopes and later electron microscopes helped scientists learn more about the cell. Most of the discoveries about cell structure since the 1950s have been made due to the use of electron microscopes.
- The cell theory states that all living things are made of one or more cells, that cells are the basic unit of life, and that cells come only from other cells.
- Cell size is limited by a cell's surface area to volume ratio. A cell's shape is determined by its function.
- Parts common to all cells are the plasma membrane, the cytoplasm, ribosomes, and genetic material.
- Prokaryotic cells lack a nucleus and other membrane-bound organelles.

Review Questions

1. Describe the contributions of Hooke and Leeuwenhoek to cell biology.
2. What enabled Leeuwenhoek to observe things that nobody else had seen before?
3. What three things does the cell theory propose?
4. A cell has a volume of 64 units, and total surface area of 96 units. What is the cell's surface area to volume ratio (surface area ÷ volume)?
5. What is the relationship between cell shape and function?
6. What are the three basic parts of a cell?
7. Compare prokaryotic and eukaryotic cells. Identify two differences between prokaryotic and eukaryotic cells.
8. Is the cell in this image prokaryotic or eukaryotic? Explain your answer.

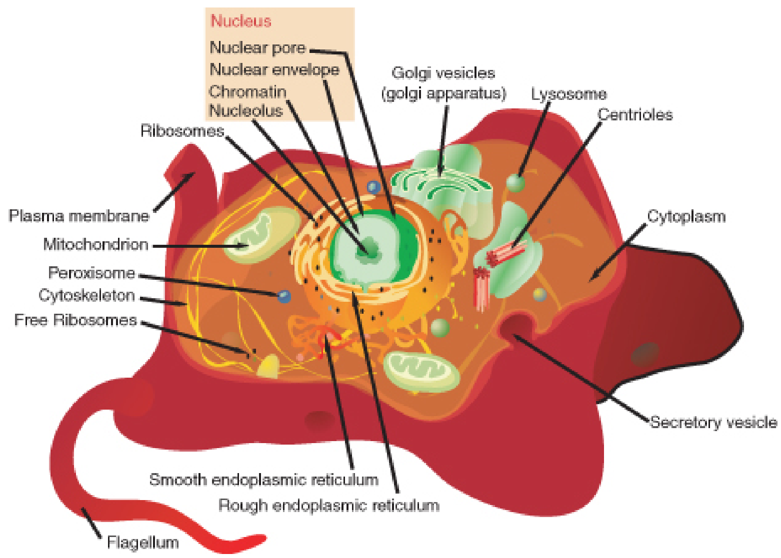

Figure 1.12

Further Reading / Supplemental Links

- Human Anatomy © 2003 Martini, Timmons, Tallitsch. Published by Prentice Hall, Inc.
- http://www.ucmp.berkeley.edu/history/hooke.htmlhttp://www.ucmp.berkeley.edu/history/hooke.html
- http://www.ucmp.berkeley.edu/history/leeuwenhoek.htmlhttp://www.ucmp.berkeley.edu/history/leeuwenhoek.html
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- http://www.ucmp.berkeley.edu/history/hooke.htmlhttp://www.ucmp.berkeley.edu/history/hooke.html
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- http://en.wikipedia.orghttp://en.wikipedia.org
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Vocabulary

cell The smallest unit that can carry out the processes of life; the basic unit of all living things.

cell membrane The physical boundary between the inside of the cell (intracellular) and its outside environment (extracellular).

cytoplasm The general term for all of the material inside the cell, between the cell membrane and the nucleus.

cytosol A watery fluid that contains dissolved particles and organelles; makes up cytoplasm.

DNA Deoxyribonucleic acid, the genetic material; contains the genetic information needed for building structures such as proteins.

eukaryote An organism whose cells are organized into complex structures by internal membranes and a cytoskeleton.

eukaryotic cells Typical of multi-celled organisms; have membrane bound organelles; usually larger than prokaryotic cells.

nucleus The membrane bound organelle that contains DNA; found in eukaryotic cells.

organelle Structure that carries out specific functions inside the cell.

prokaryotic cells Typical of simple, single-celled organisms, such as bacteria; lack a nucleus and other membrane bound organelles.

resolution A measure of the clarity of an image; the minimum distance that two points can be separated by and still be distinguished as two separate points.

ribosomes The organelles on which proteins are made (synthesized).

Points to Consider

Next we focus on cell structures and their roles.

- What do you think is the most important structure in a cell? Why?
- Using each of the functions of the four common cell parts, state why each one is necessary for the survival of the cell.

Lesson 3.2: Cell Structures

Lesson Objectives

- Outline the structure of the plasma membrane.
- Distinguish cytoplasm from cytosol.
- Name three types of protein fibers that make up the cytoskeleton.
- Compare and and contrast plant and animal cells
- List three major organelles found only in eukaryotic cells and identify their roles.
- Given medical conditions, determine what cell's structure and function is affected and why.
- Be able to relate all organelles involved in the production of proteins

Introduction

The invention of the microscope opened up a previously unknown world. Before the invention of the microscope, very little was known about what made up living things and non-living things, or where living things came from. During Hooke's and Leeuwenhoek's time, spontaneous generation — the belief that living organisms grow directly from decaying organic substances — was the accepted explanation for the appearance of small organisms. For example, people accepted that mice spontaneously appeared in stored grain, and maggots formed in meat with no apparent external influence. Once cells were discovered, the search for answers to such questions as "what are cells made of?" and "what do they do?" became the focus of study.

Cell Function

Cells share the same needs: the need to get energy from their environment, the need to respond to their environment, and the need to reproduce. Cells must also be able to separate their relatively stable interior from the ever-changing external environment. They do this by coordinating many processes that are carried out in different parts of the cell. Structures that are common to many different cells indicate the common history shared by cell-based life. Examples of these common structures include the components of both the cell (or plasma) membrane and the cytoskeleton, and other structures shown in **Figure** 1.13.

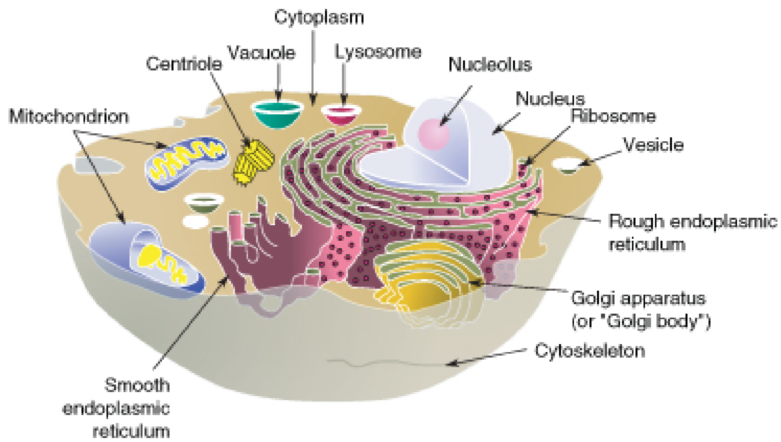


Figure 1.13: The structure and contents of a typical animal cell. Every animal cell has a cell membrane, cytoplasm, and a nucleus, but not all cells have every structure shown here. For example, some cells such as red blood cells do not have any mitochondria, yet others such as muscle cells may have thousands of mitochondria.

Plasma Membrane

The plasma membrane (also called the cell membrane) has many functions. For example, it separates the internal environment of the cell from the outside environment. It allows only certain molecules into and out of the cell. The ability to allow only certain molecules in or out of the cell is referred to as **selective permeability** or semipermeability. The plasma membrane also acts as the attachment point for both the intracellular cytoskeleton and, if present, the cell wall.

The plasma membrane is a lipid bilayer that is common to all living cells. A **lipid bilayer** is a double layer of closely-packed lipid molecules. The membranes of cell organelles are also lipid bilayers. The plasma membrane contains many different biological molecules, mostly lipids and proteins. These lipids and proteins are involved in many cellular processes.

Phospholipids

The main type of lipid found in the plasma membrane is phospholipid. A phospholipid is made up of a polar, phosphorus-containing head, and two long fatty acid, non-polar "tails." That is, the head of the molecule is hydrophilic (water-loving), and the tail is hydrophobic (water-fearing). Cytosol and extracellular fluid are made up of mostly water. In this watery environment, the water loving heads point out towards the water, and the water fearing tails point inwards, and push the water out. The resulting double layer is called a phospholipid bilayer. A **phospholipid bilayer** is made up of two layers of phospholipids, in which hydrophobic fatty acids are in the middle of the plasma membrane, and the hydrophilic heads are on the outside. An example of a simple phospholipid bilayer is illustrated in **Figure** 1.14.

Plasma membranes of eukaryotes contain many proteins, as well as other lipids called sterols. The proteins have various functions, such as channels that allow certain molecules into the cell and receptors that bind to signal molecules. In **Figure** 1.14, the smaller (green) molecules shown between the phospholipids are cholesterol molecules. Cholesterol helps keep the plasma membrane firm and stable over a wide range of

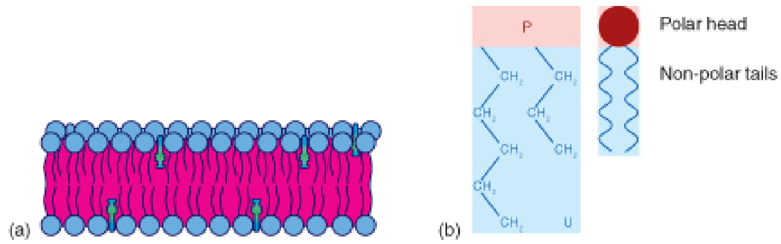


Figure 1.14: The hydrophobic fatty acids point towards the middle of the plasma membrane (pink), and the hydrophilic heads (blue) point outwards. The membrane is stabilized by cholesterol molecules (green). This self-organization of phospholipids results in a selectively permeable membrane which allows only certain molecules in or out of the cell.

temperatures. At least ten different types of lipids are commonly found in plasma membranes. Each type of cell or organelle will have a different percentage of each lipid, protein and carbohydrate.

Membrane Proteins

Plasma membranes also contain certain types of proteins. A **membrane protein** is a protein molecule that is attached to, or associated with the membrane of a cell or an organelle. Membrane proteins can be put into two groups based on how the protein is associated with the membrane.

Integral membrane proteins are permanently embedded within the plasma membrane. They have a range of important functions. Such functions include channeling or transporting molecules across the membrane. Other integral proteins act as cell receptors. Integral membrane proteins can be classified according to their relationship with the bilayer:

- Transmembrane proteins span the entire plasma membrane. Transmembrane proteins are found in all types of biological membranes.
- Integral monotopic proteins are permanently attached to the membrane from only one side.

Some integral membrane proteins are responsible for cell adhesion (sticking of a cell to another cell or surface). On the outside of cell membranes and attached to some of the proteins are carbohydrate chains that act as labels that identify the cell type. Shown in **Figure** 1.15 are two different types of membrane proteins and associated molecules.

Peripheral membrane proteins are proteins that are only temporarily associated with the membrane. They can be easily removed, which allows them to be involved in cell signaling. Peripheral proteins can also be attached to integral membrane proteins, or they can stick into a small portion of the lipid bilayer by themselves. Peripheral membrane proteins are often associated with ion channels and transmembrane receptors. Most peripheral membrane proteins are hydrophilic.

Fluid Mosaic Model

In 1972 S.J. Singer and G.L. Nicolson proposed the now widely accepted Fluid Mosaic Model of the structure of cell membranes. The model proposes that integral membrane proteins are embedded in the phospholipid

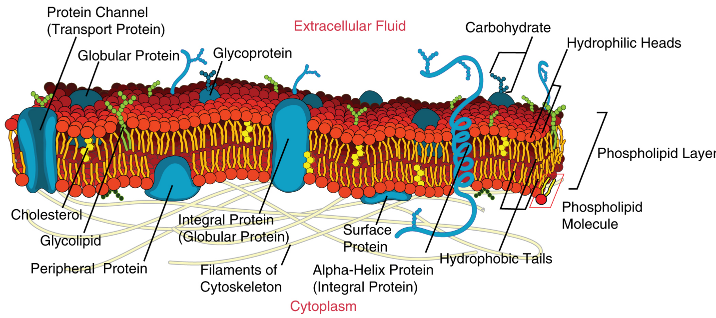


Figure 1.15: Some of the membrane proteins make up a major transport system that moves molecules and ions through the polar phospholipid bilayer.

bilayer, as seen in **Figure** 1.15. Some of these proteins extend all the way through the bilayer, and some only partially across it. These membrane proteins act as transport proteins and receptors proteins.

Their model also proposed that the membrane behaves like a fluid, rather than a solid. The proteins and lipids of the membrane move around the membrane, much like buoys in water. Such movement causes a constant change in the "mosaic pattern" of the plasma membrane.

Cytoplasm

The gel-like material within the cell that holds the organelles is called **cytoplasm**. The cytoplasm plays an important role in a cell, serving as a "jelly" in which organelles are suspended and held together by a fatty membrane. The **cytosol**, which is the watery substance that does not contain organelles, is made up of 80% to 90% water.

The cytosol plays a mechanical role by exerting pressure against the cell's plasma membrane which helps keep the shape of the cell. Cytosol also acts as the site of biochemical reactions such as anaerobic glycolysis and protein synthesis. In prokaryotes all chemical reactions take place in the cytosol.

Cytoskeleton

The **cytoskeleton** is a cellular "scaffolding" or "skeleton" that crisscrosses the cytoplasm. All eukaryotic cells have a cytoskeleton, and recent research has shown that prokaryotic cells also have a cytoskeleton. The eukaryotic cytoskeleton is made up of a network of long, thin protein fibers and has many functions. It helps to maintain cell shape. It holds organelles in place, and for some cells, it enables cell movement. The cytoskeleton also plays important roles in both the intracellular movement of substances and in cell division. Certain proteins act like a path that vesicles and organelles move along within the cell. The threadlike proteins that make up the cytoskeleton continually rebuild to adapt to the cell's constantly changing needs. Three main kinds of cytoskeleton fibers are microtubules, intermediate filaments, and microfilaments.

- **Microtubules**, shown in **Figure** 1.16 **(a)**, are hollow cylinders and are the thickest of the cytoskeleton structures. They are most commonly made of filaments which are polymers of alpha and beta tubulin, and radiate outwards from an area near the nucleus called the centrosome. Tubulin is a protein that is composed of hollow cylinders which are made of two protein chains that are twisted around each other. Microtubules help keep cell shape. They hold organelles in place and allow them to move around the cell, and they form the mitotic spindle during cell division. Microtubules also make up parts of cilia and flagella, the organelles that help a cell to move.

- **Microfilaments**, shown in **Figure** 1.16 **(b)**, are made of two thin actin chains that are twisted around one another. Microfilaments are mostly concentrated just beneath the cell membrane where they support the cell and help keep the cell's shape. Microfilaments form cytoplasmatic extentions such as pseudopodia and microvilli which allows certain cells to move. The actin of the microfilaments interacts with the protein myosin to cause contraction in muscle cells. Microfilaments are found in almost every cell, and are numerous in muscle cells and in cells that move by changing shape such as phagocytes (white blood cells that search the body for bacteria and other invaders).
- **Intermediate filament**, shown in **Figure** 1.16 **(c)**, make-up differs from one cell type to another. Intermediate filaments organize the inside structure of the cell by holding organelles and providing strength. They are also structural components of the nuclear envelope. Intermediate filaments made of the protein keratin are found in skin, hair, and nails cells.

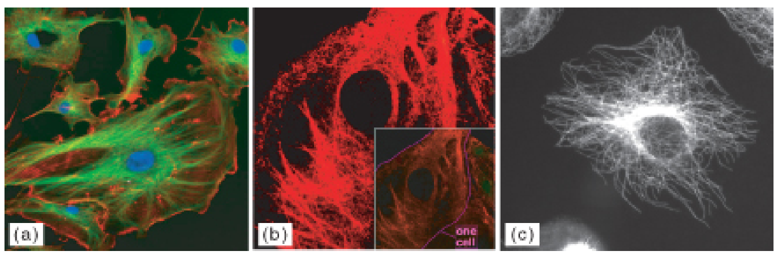
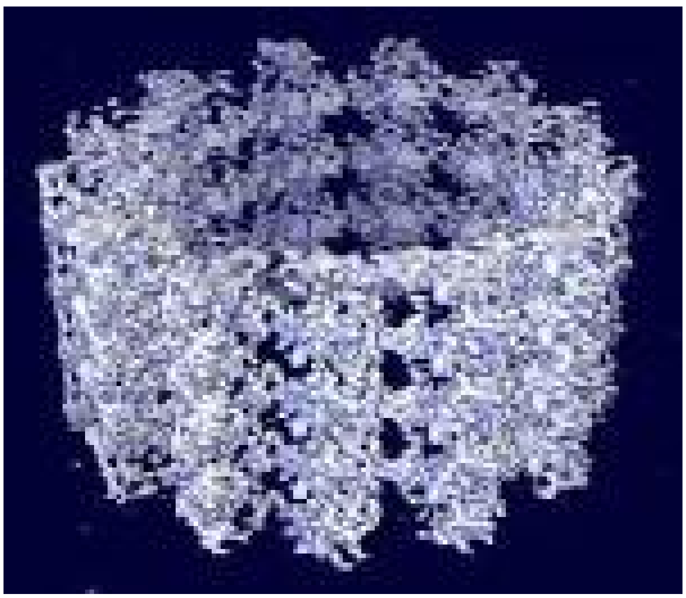


Figure 1.16: The eukaryotic cytoskeleton. Microfilaments are shown in red, microtubules in green, and the nuclei are in blue. By linking regions of the cell together, the cytoskeleton helps support the shape of the cell. Microscopy of keratin filaments (intermediate filaments) inside cells. Microtubules in a methanol-fixated cell, visualized with anti-beta-tubuline antibodies.

Table 1.2: Molecular structure of microtubules.Keratin intermediate filaments in skin cells (stained red).Actin cytoskeleton of mouse embryo cells.Cytoskeleton Structure

	Microtubules	Intermediate Filaments	Microfilaments
Fiber Diameter	about 25 nm	8 to 11 nm	around 7 nm
Protein Composition	tubulin, with two subunits, alpha and beta tubulin	One of different types of proteins such as lamin, vimentin, and keratin	actin
Shape	hollow cylinders made of two protein chains twisted around each other	protein fiber coils twisted into each other	two actin chains twisted around one another

Table 1.2: (continued)

	Microtubules	Intermediate Filaments	Microfilaments
Main Functions	organelle and vesicle movement; form mitotic spindles during cell reproduction; cell motility (in cilia and flagella)	organize cell shape; positions organelles in cytoplasm structural support of the nuclear envelope and sarcomeres; involved in cell-to-cell and cell-to-matrix junctions	keep cellular shape; allows movement of certain cells by forming cytoplasmatic extensions or contraction of actin fibers; involved in some cell-to-cell or cell-to-matrix junctions
Image			

External Structures

Flagella (flagellum, singular) are long, thin structures that stick out from the cell membrane. Both eukaryotic and prokaryotic cells can have flagella. Flagella help single-celled organisms move or swim towards food. The flagella of eukaryotic cells are normally used for movement too, such as in the movement of sperm cells. The flagella of either group are very different from each other. Prokaryotic flagella, shown in **Figure** 1.17, are spiral-shaped and stiff. They spin around in a fixed base much like a screw does, which moves the cell in a tumbling fashion. Eukaryotic flagella are made of microtubules and bend and flex like a whip.

Cilia (cilium, singular) are made up of extensions of the cell membrane that contain microtubules. Although both are used for movement, cilia are much shorter than flagella. Cilia cover the surface of some single-celled organisms, such as paramecium. Their cilia beat together to move the little animals through the water. In

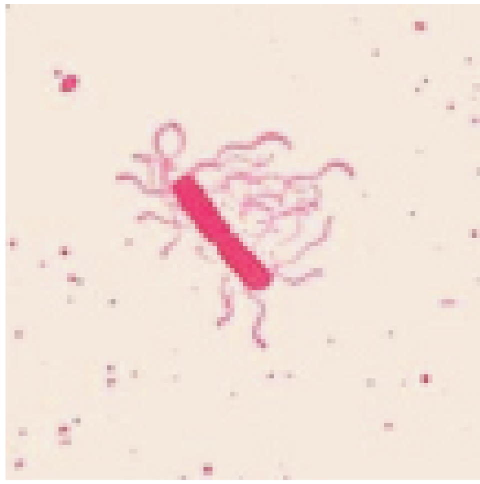


Figure 1.17: Bacterial flagella spin about in place, which causes the bacterial cell to "tumble."

multicellular animals, including humans, cilia are usually found in large numbers on a single surface of cells. Multicellular animals' cilia usually move materials inside the body. For example, the mucociliary escalator of the respiratory system is made up of mucus-secreting cells that line the trachea and bronchi. Ciliated cells, shown in **Figure** 1.18, move mucus away from the lungs. Spores, bacteria, and debris are caught in the mucus which is moved to the esophagus by the ciliated cells, where it is swallowed.

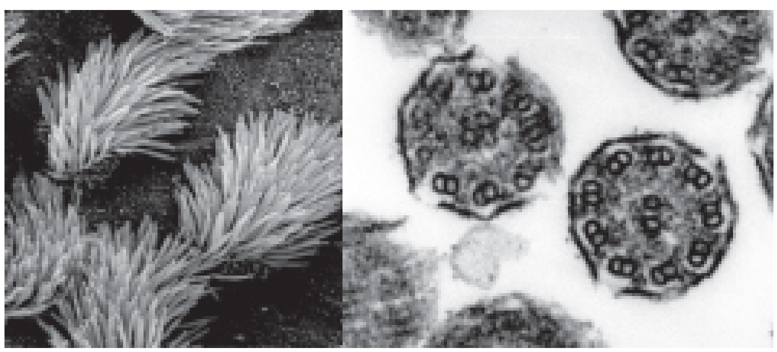


Figure 1.18: Left: Scanning electron micrograph (SEM), of the cilia sticking up from human lung cells. Right: Electron micrograph of cross-section of two cilia (not human), showing the positions of the microtubules inside. Note how there are nine groups of two microtubules (called dimers) in each cilium. Each dimer is made up of an alpha and a beta tubulin protein that are connected together.

The Nucleus and Other Organelles

The nucleus is a membrane-enclosed organelle found in most eukaryotic cells. The nucleus is the largest organelle in the cell and contains most of the cell's genetic information (mitochondria also contain DNA, called mitochondrial DNA, but it makes up just a small percentage of the cell's overall DNA content). The genetic information, which contains the information for the structure and function of the organism, is found encoded in DNA in the form of genes. A **gene** is a short segment of DNA that contains information to encode an RNA molecule or a protein strand. DNA in the nucleus is organized in long linear strands that are attached to different proteins. These proteins help the DNA to coil up for better storage in the nucleus. Think how a string gets tightly coiled up if you twist one end while holding the other end. These long strands of coiled-up DNA and proteins are called **chromosomes**. Each chromosome contains many genes. The function of the nucleus is to maintain the integrity of these genes and to control the activities of the cell by regulating gene expression. **Gene expression** is the process by which the information in a gene is "decoded" by various cell molecules to produce a functional gene product, such as a protein molecule or an RNA molecule.

The degree of DNA coiling determines whether the chromosome strands are short and thick or long and thin. Between cell divisions, the DNA in chromosomes is more loosely coiled and forms long thin strands called chromatin. Before the cell divides, the chromatin coil up more tightly and form chromosomes. Only chromosomes stain clearly enough to be seen under a microscope. The word chromosome comes from the Greek word chroma, (color) and soma, (body) due to its ability to be stained strongly by dyes.

Nuclear Envelope

The **nuclear envelope** is a double membrane of the nucleus that encloses the genetic material. It separates the contents of the nucleus from the cytoplasm. The nuclear envelope is made of two lipid bilayers, an inner membrane and an outer membrane. The outer membrane is continuous with the rough endoplasmic reticulum. Many tiny holes called nuclear pores are found in the nuclear envelope. These nuclear pores help to regulate the exchange of materials (such as RNA and proteins) between the nucleus and the cytoplasm.

Nucleolus

The nucleus of many cells also contains an organelle called a **nucleolus**, shown in **Figure** 1.19. The nucleolus is mainly involved in the assembly of ribosomes. **Ribosomes** are organelles made of protein and ribosomal RNA (rRNA), and they build cellular proteins in the cytoplasm. The function of the rRNA is to provide a way of decoding the genetic messages within another type of RNA called mRNA, into amino acids. After being made in the nucleolus, ribosomes are exported to the cytoplasm where they direct protein synthesis.

Centrioles

Centrioles are rod-like structures made of short microtubules. Nine groups of three microtubules make up each centriole. Two perpendicularly placed centrioles make up the centrosome. Centrioles are very important in cellular division, where they arrange the mitotic spindles that pull the chromosome apart during mitosis.

Mitochondria

A **mitochondrion** (mitochondria, plural), is a membrane-enclosed organelle that is found in most eukaryotic cells. Mitochondria are called the "power plants" of the cell because they use energy from organic compounds to make ATP. ATP is the cell's energy source that is used for such things such as movement and cell division. Some ATP is made in the cytosol of the cell, but most of it is made inside mitochondria. The number of

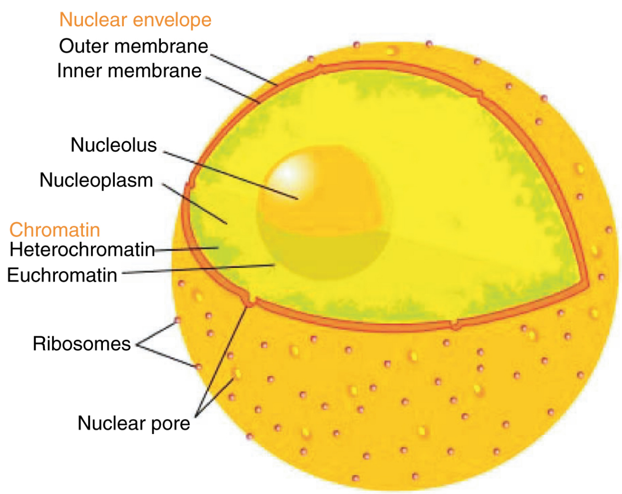


Figure 1.19: The eukaryotic cell nucleus. Visible in this diagram are the ribosome-studded double membranes of the nuclear envelope, the DNA (as chromatin), and the nucleolus. Within the cell nucleus is a viscous liquid called nucleoplasm, similar to the cytoplasm found outside the nucleus. The chromatin (which is normally invisible), is visible in this figure only to show that it is spread out throughout the nucleus.

mitochondria in a cell depends on the cell's energy needs. For example, active human muscle cells may have thousands of mitochondria, while less active red blood cells do not have any.

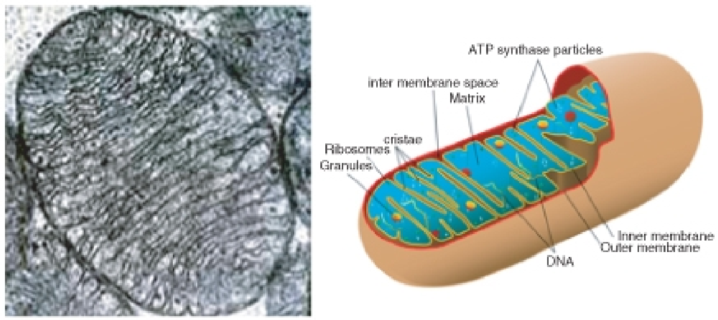


Figure 1.20: Electron micrograph of a single mitochondrion within which you can see many cristae. Mitochondria range from 1 to 10 m in size. This model of a mitochondrian shows the organized arrangement of the inner and outer membranes, the protein matrix, and the folded inner mitochondrial membranes.

As **Figure** 1.20 **(a) and (b)** shows, a mitochondrion has two phospholipids membranes. The smooth outer membrane separates the mitochondrion from the cytosol. The inner membrane has many folds, called cristae. The fluid-filled inside of the mitochondrian, called matrix, is where most of the cell's ATP is made.

Although most of a cell's DNA is contained in the cell nucleus, mitochondria have their own DNA. Mitochandria are able to reproduce asexually and scientists think that they are descended from prokaryotes. According to the endosymbiotic theory, mitochondria were once free-living prokaryotes that infected ancient eukaryotic cells. The invading prokaryotes were protected inside the eukaryotic host cell, and in turn the prokaryote supplied extra ATP to its host.

Endoplasmic Reticulum

The **endoplasmic reticulum (ER)** (plural, reticuli) is a network of phospholipid membranes that form hollow tubes, flattened sheets, and round sacs. These flattened, hollow folds and sacs are called cisternae. The ER has two major functions:

- **Transport**: Molecules, such as proteins, can move from place to place inside the ER, much like on an intracellular highway.
- **Synthesis**: Ribosomes that are attached to ER, similar to unattached ribosomes, make proteins. Lipids are also produced in the ER.

There are two types of endoplasmic reticulum, rough endoplasmic reticulum (RER) and smooth endoplasmic reticulum (SER).

- **Rough endoplasmic reticulum** is studded with ribosomes which gives it a "rough" appearance. These ribosomes make proteins that are then transported from the ER in small sacs called transport vesicles. The transport vesicles pinch off the ends of the ER. The rough endoplasmic reticulum works with the Golgi apparatus to move new proteins to their proper destinations in the cell. The membrane of the RER is continuous with the outer layer of the nuclear envelope.

- **Smooth endoplasmic reticulum** does not have any ribosomes attached to it, and so it has a smooth appearance. SER has many different functions some of which are: lipid synthesis, calcium ion storage, and drug detoxification. Smooth endoplasmic reticulum is found in both animal and plant cells and it serves different functions in each. The SER is made up of tubules and vesicles that branch out to form a network. In some cells there are dilated areas like the sacs of RER. Smooth endoplasmic reticulum and RER form an interconnected network.

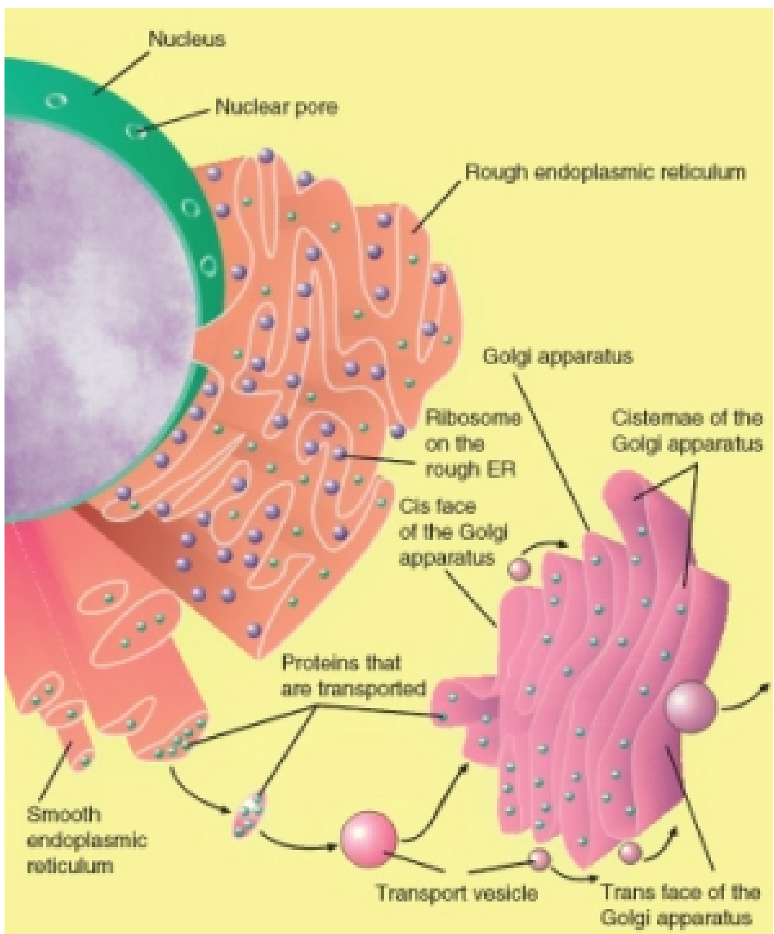


Figure 1.21: Image of nucleus, endoplasmic reticulum and Golgi apparatus, and how they work together. The process of secretion from endoplasmic reticuli (orange) to Golgi apparatus (pink) is shown.

Ribosomes

Ribosomes are small organelles and are the site of protein synthesis (or assembly). They are made of ribosomal protein and ribosomal RNA. Each ribosome has two parts, a large and a small subunit, as shown in **Figure** 1.22. The subunits are attached to each other. Ribosomes can be found alone or in groups within the cytoplasm. Some ribosomes are attached to the endoplasmic reticulum (as shown in **Figure** 1.21), and others are attached to the nuclear envelope.

Ribozymes are RNA molecules that catalyzes chemical reactions, such as translation. Translation is the process of ordering the amino acids in the assembly of a protein, and more will be discussed on translation in a later chapter. Briefly, the ribosomes interact with other RNA molecules to make chains of amino acids called polypeptide chains, due to the peptide bond that forms between individual amino acids. Polypeptide chains are built from the genetic instructions held within a messenger RNA molecule. Polypeptide chains that are made on the rough ER are inserted directly into the ER and then are transported to their various cellular destinations. Ribosomes on the rough ER usually produce proteins that are destined for the cell membrane.

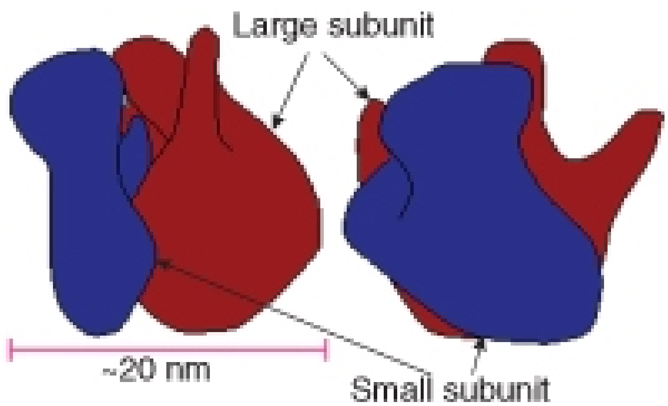


Figure 1.22: The two subunits that make up a ribosome, small organelles that are intercellular protein factories.

Golgi Apparatus

The **Golgi apparatus** is a large organelle that is usually made up of five to eight cup-shaped, membrane-covered discs called cisternae, as shown in **Figure** 1.21. The cisternae look a bit like a stack of deflated balloons. The Golgi apparatus modifies, sorts, and packages different substances for secretion out of the cell, or for use within the cell. The Golgi apparatus is found close to the nucleus of the cell where it modifies proteins that have been delivered in transport vesicles from the RER. It is also involved in the transport of lipids around the cell. Pieces of the Golgi membrane pinch off to form vesicles that transport molecules around the cell. The Golgi apparatus can be thought of as similar to a post office; it packages and labels "items" and then sends them to different parts of the cell. Both plant and animal cells have a Golgi apparatus.

Plant cells can have up to several hundred Golgi stacks scattered throughout the cytoplasm. In plants, the Golgi apparatus contains enzymes that synthesize some of the cell wall polysaccharides.

Vesicles

A **vesicle** is a small, spherical compartment that is separated from the cytosol by at least one lipid bilayer. Many vesicles are made in the Golgi apparatus and the endoplasmic reticulum, or are made from parts of the cell membrane. Vesicles from the Golgi apparatus can be seen in **Figure** 1.21. Because it is separated from the cytosol, the space inside the vesicle can be made to be chemically different from the cytosol. Vesicles are basic tools of the cell for organizing metabolism, transport, and storage of molecules. Vesicles are also used as chemical reaction chambers. They can be classified by their contents and function.

- **Transport vesicles** are able to move molecules between locations inside the cell. For example, transport vesicles move proteins from the rough endoplasmic reticulum to the Golgi apparatus.
- **Lysosomes** are vesicles that are formed by the Golgi apparatus. They contain powerful enzymes that could break down (digest) the cell. Lysosomes break down harmful cell products, waste materials, and cellular debris and then force them out of the cell. They also digest invading organisms such as bacteria. Lysosomes also break down cells that are ready to die, a process called autolysis.
- **Peroxisomes** are vesicles that use oxygen to break down toxic substances in the cell. Unlike lysosomes, which are formed by the Golgi apparatus, peroxisomes self replicate by growing bigger and then dividing. They are common in liver and kidney cells that break down harmful substances. Peroxisomes are named for the hydrogen peroxide (H_2O_2) that is produced when they break down organic compounds. Hydrogen peroxide is toxic, and in turn is broken down into water (H_2O) and oxygen (O_2) molecules.

Vacuoles

Vacuoles are membrane-bound organelles that can have secretory, excretory, and storage functions. Many organisms will use vacuoles as storage areas and some plant cells have very large vacuoles. Vesicles are much smaller than vacuoles and function in transporting materials both within and to the outside of the cell.

Special Structures in Plant Cells

Most of the organelles that have been discussed are common to both animal and plant cells. However, plant cells also have features that animal cells do not have; they have a cell wall, a large central vacuole, and plastids such as chloroplasts.

Plants have very different lifestyles from animals, and these differences are apparent when you examine the structure of the plant cell. Plants make their own food in a process called photosynthesis. They take in carbon dioxide (CO_2) and water (H_2O) and convert them into sugars. The features unique to plant cells can be seen in **Figure** 1.23.

Cell Wall

A cell wall is a rigid layer that is found outside the cell membrane and surrounds the cell. The cell wall contains not only cellulose and protein, but other polysaccharides as well. In fact, two other classes of

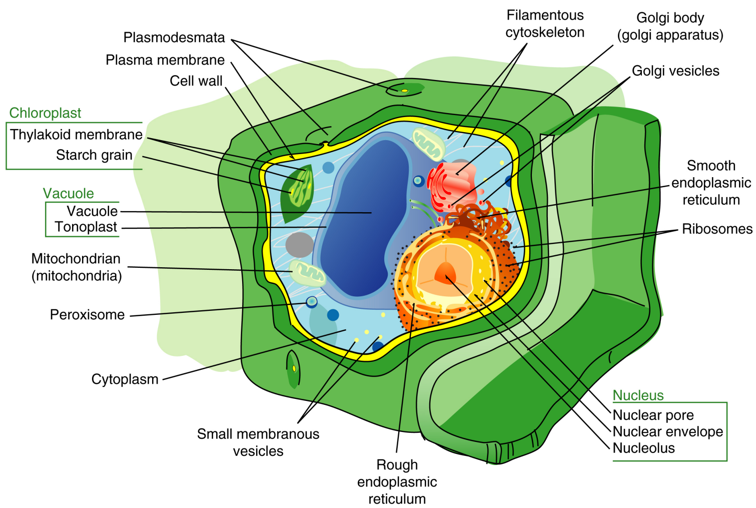


Figure 1.23: In addition to containing most of the organelles found in animal cells, plant cells also have a cell wall, a large central vacuole, and plastids. These three features are not found in animal cells.

polysaccharides, hemicelluloses and pectic polysaccharides, can comprise 30% of the dry mass of the cell wall. The cell wall provides structural support and protection. Pores in the cell wall allow water and nutrients to move into and out of the cell. The cell wall also prevents the plant cell from bursting when water enters the cell.

Microtubules guide the formation of the plant cell wall. Cellulose is laid down by enzymes to form the primary cell wall. Some plants also have a secondary cell wall. The secondary wall contains a lignin, a secondary cell component in plant cells that have completed cell growth/expansion.

Central Vacuole

Most mature plant cells have a **central vacuole** that occupies more than 30% of the cell's volume, but can also occupy as much as 90% of the volume of certain cells. The central vacuole is surrounded by a membrane called the tonoplast. The central vacuole has many functions. Aside from storage, the main role of the vacuole is to maintain turgor pressure against the cell wall. Proteins found in the tonoplast control the flow of water into and out of the vacuole. The central vacuole also stores the pigments that color flowers.

The central vacuole contains large amounts of a liquid called cell sap, which differs in composition to the cell cytosol. Cell sap is a mixture of water, enzymes, ions, salts, and other substances. Cell sap may also contain toxic byproducts that have been removed from the cytosol. Toxins in the vacuole may help to protect some plants from being eaten.

Plastids

Plant plastids are a group of closely related membrane-bound organelles that carry out many functions. They are responsible for photosynthesis, for storage of products such as starch, and for the synthesis of many types of molecules that are needed as cellular building blocks. Plastids have the ability to change their function between these and other forms. Plastids contain their own DNA and some ribosomes, and scientists think that plastids are descended from photosynthetic bacteria that allowed the first eukaryotes to make oxygen. The main types of plastids and their functions are:

- **Chloroplasts** are the organelle of photosynthesis. They capture light energy from the sun and use it with water and carbon dioxide to make food (sugar) for the plant. The arrangement of chloroplasts in a plant's cells can be seen in **Figure** 1.24.
- **Chromoplasts** make and store pigments that give petals and fruit their orange and yellow colors.
- **Leucoplasts** do not contain pigments and are located in roots and non-photosynthetic tissues of plants. They may become specialized for bulk storage of starch, lipid, or protein. However, in many cells, leucoplasts do not have a major storage function; instead they make molecules such as fatty acids and many amino acids.

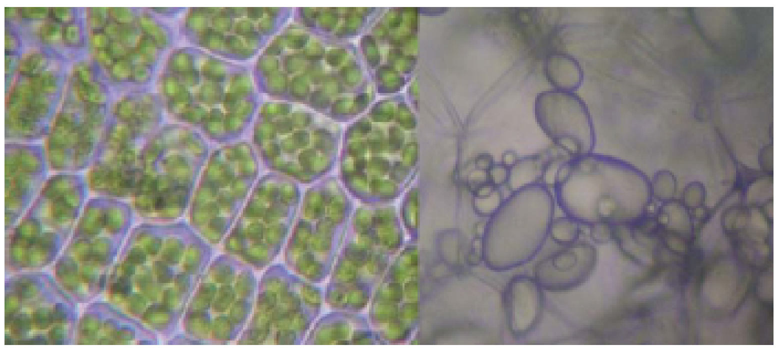


Figure 1.24: Plant cells with visible chloroplasts (left). Starch-storing potato leucoplasts (right).

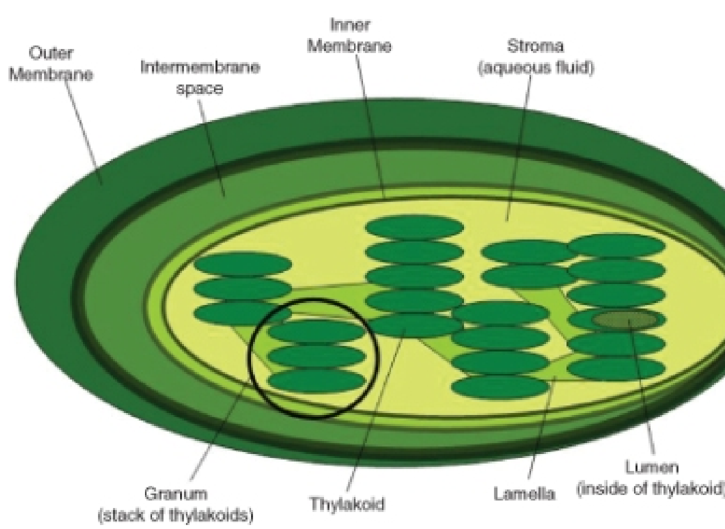


Figure 1.25: The internal structure of a chloroplast, with a granal stack of thylakoids circled.

Chloroplasts capture light energy from the sun and use it with water and carbon dioxide to produce sugars for food. Chloroplasts look like flat discs that are usually 2 to 10 micrometers in diameter and 1 micrometer thick. A model of a chloroplast is shown in **Figure** 1.25. The chloroplast is enclosed by an inner and an outer phospholipid membrane. Between these two layers is the intermembrane space. The fluid within the chloroplast is called the **stroma**, and it contains one or more molecules of small circular DNA. The stroma also has ribosomes. Within the stroma are stacks of **thylakoids**, the sub-organelles which are the site of photosynthesis. The thylakoids are arranged in stacks called **grana** (singular: granum). A thylakoid has a flattened disk shape. Inside it is an empty area called the thylakoid space or lumen. Photosynthesis takes place on the thylakoid membrane.

Within the thylakoid membrane is the complex of proteins and light-absorbing pigments, such as chlorophyll and carotenoids. This complex allows capture of light energy from many wavelengths because chlorophyll and carotenoids both absorb different wavelengths of light. You will learn more about how chloroplasts convert light energy into chemical energy in the Photosynthesis chapter.

Organization of Cells

Biological organization exists at all levels in organisms. It can be seen at the smallest level, in the molecules that made up such things as DNA and proteins, to the largest level, in an organism such as a blue whale, the largest mammal on Earth. Similarly, single celled prokaryotes and eukaryotes show order in the way their cells are arranged. Single-celled organisms such as an amoeba are free-floating and independent-living. Their single-celled "bodies" are able to carry out all the processes of life such as metabolism and respiration without help from other cells. Some single-celled organisms such as bacteria can group together and form a biofilm. A **biofilm** is a large grouping of many bacteria that sticks to a surface and makes a protective coating over itself. Biofilms can show similarities to multicellular organisms. Division of labor is the process in which one group of cells does one job (such as making the "glue" that sticks the biofilm to the surface) while another group of cells does another job (such as taking in nutrients). Multicellular organisms carry out their life processes through division of labor and they have specialized cells that do specific jobs. However, biofilms are not considered a multicellular organism and are instead called colonial organisms. The difference between a multicellular organism and a colonial organism is that individual organisms from a colony or biofilm can, if separated, survive on their own, while cells from a multicellular organism (e.g., liver cells) cannot.

Colonial Organisms

Colonial organisms were probably one of the first evolutionary steps towards multicellular organisms. Algae of the genus *Volvox* are an example of the border between colonial organisms and multicellular organisms.

Each *Volvox*, shown in **Figure** 1.26, is a colonial organism. It is made up of between 1000 to 3000 photosynthetic algae that are grouped together into a hollow sphere. The sphere has a distinct front and back end. The cells have eyespots, which are more developed in the cells near the front. This enables the colony to swim towards light.

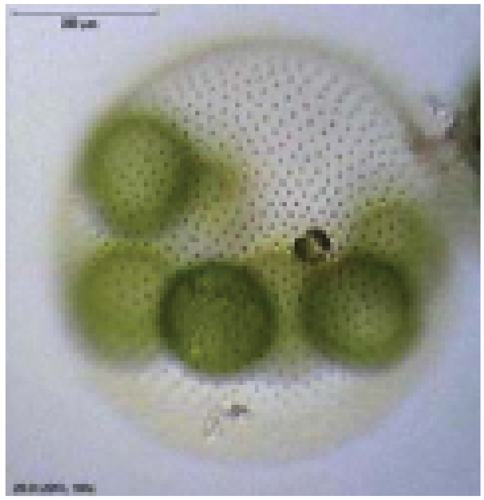


Figure 1.26: Colonial algae of the genus .

Origin of Multicellularity

The oldest known multicellular organism is a red algae *Bangiomorpha pubescens*, fossils of which were found in 1.2 billion year old rock. However, the first organisms were single celled. How multicellular organisms developed is the subject of much debate.

Scientists think that multicellularity arose from cooperation between many organisms of the same species. The **Colonial Theory** proposes that this cooperation led to the development of a multicellular organism. Many examples of cooperation between organisms in nature have been observed. For example, a certain species of amoeba (a single-celled animal) groups together during times of food shortage and forms a colony that moves as one to a new location. Some of these amoebas then become slightly differentiated from each other. *Volvox*, shown in **Figure** 1.26, is another example of a colonial organism. Most scientists accept that the Colonial theory explains how multicellular organisms evolved.

Multicellular organisms are organisms that are made up of more than one type of cell and have specialized cells that are grouped together to carry out specialized functions. Most life that you can see without a microscope is multicellular. As discussed earlier, the cells of a multicellular organism would not survive as independent cells. The body of a multicellular organism, such as a tree or a cat, exhibits organization at several levels: tissues, organs, and organ systems. Similar cells are grouped into tissues, groups of tissues make up organs, and organs with a similar function are grouped into an organ system.

Levels of Organization in Multicellular Organisms

The simplest living multicellular organisms, sponges, are made of many specialized types of cells that work together for a common goal. Such cell types include digestive cells, tubular pore cells; and epidermal cells. Though the different cell types create a large organized, multicellular structure—the visible sponge—they are not organized into true interconnected tissues. If a sponge is broken up by passing it through a sieve, the sponge will reform on the other side. However, if the sponge's cells are separated from each other, the individual cell types cannot survive alone. Simpler colonial organisms, such as members of the genus *Volvox*, as shown in **Figure** 1.26, differ in that their individual cells are free-living and can survive on their own if separated from the colony.

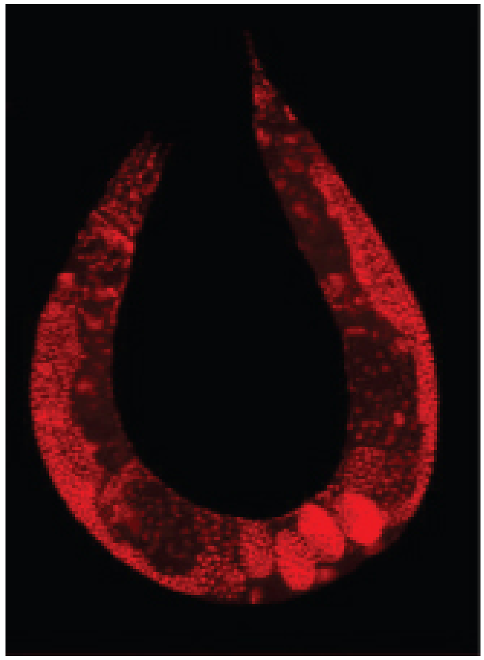


Figure 1.27: This roundworm, a multicellular organism, was stained to highlight the nuclei of all the cells in its body (red dots).

A **tissue** is a group of connected cells that have a similar function within an organism. More complex organisms such as jellyfish, coral, and sea anemones have a tissue level of organization. For example, jellyfish have tissues that have separate protective, digestive, and sensory functions.

Even more complex organisms, such as the roundworm shown in **Figure** 1.27, while also having differentiated cells and tissues, have an organ level of development. An **organ** is a group of tissues that has a specific function or group of functions. Organs can be as primitive as the brain of a flatworm (a group of nerve cells), as large as the stem of a sequoia (up to 90 meters, or 300 feet, in height), or as complex as a human liver.

The most complex organisms (such as mammals, trees, and flowers) have organ systems. An **organ system** is a group of organs that act together to carry out complex related functions, with each organ focusing on a part of the task. An example is the human digestive system in which the mouth ingests food, the stomach crushes and liquifies it, the pancreas and gall bladder make and release digestive enzymes, and the intestines absorb nutrients into the blood.

Lesson Summary

- The plasma membrane is a selectively permeable lipid bilayer that contains mostly lipids and proteins. These lipids and proteins are involved in many cellular processes.
- The gel-like material within the cell that holds the organelles is called cytoplasm. The cytosol, which is the watery substance that does not contain organelles, is made up of 80% to 90% water.
- The cytoskeleton has many functions. It helps to maintain cell shape, it holds organelles in place, and for some cells, it enables cell movement. The cytoskeleton also plays important roles in both the

intracellular movement of substances and in cell division. Three main kinds of cytoskeleton fibers are microtubules, intermediate filaments, and microfilaments.

- Cilia are extensions of the cell membrane that contain microtubules. Although both are used for movement, cilia are much shorter than flagella. Cilia cover the surface of some single-celled animals, such as paramecium, but cover only one side of cells in some multicellular organisms.
- There are three features that plant cells have that animal cells do not have: a cell wall, a large central vacuole, and plastids.
- Mitochondria use energy from organic compounds to make ATP.
- Ribosomes are exported from the nucleolus, where they are made, to the cytoplasm.
- The Golgi apparatus is a large organelle that is usually made up of five to eight cup-shaped, membrane-covered discs called *cisternae*. It modifies, sorts, and packages different substances for secretion out of the cell, or for use within the cell.
- Individual organisms from a colonial organism or biofilm can, if separated, survive on their own, while cells from a multicellular organism (e.g., liver cells) cannot.
- A tissue is a group of connected cells that have a similar function within an organism. An organ is a group of tissues that has a specific function or group of functions, and an organ system is a group of organs that act together to perform complex related functions, with each organ focusing on a part of the task.

Review Questions

1. What are the main components of a plasma membrane?
2. What does the fluid mosaic model describe?
3. What is the difference between cytoplasm and cytosol?
4. What type of molecule is common to all three parts of the cytoskeleton?
5. Name the three main parts of the cytoskeleton.
6. What structures do plant cells have that animal cells do not have?
7. Identify two functions of plastids in plant cells.
8. What is the main difference between rough endoplasmic reticulum and smooth endoplasmic reticulum?
9. List five organelles eukaryotes have that prokaryotes do not have.
10. What is a cell feature that distinguishes a colonial organism from a multicellular organism?
11. What is the difference between a cell and a tissue?
12. Identify two functions of the nucleus.
13. Identify the reason why mitochondria are called ”power plants” of the cell.
14. If muscle cells become more active than they usually are, they will grow more mitochondria. Explain why this happens.

Further Reading / Supplemental Links

- N. J. Butterfield (2000). Bangiomorpha pubescens n. gen., n. sp.: implications for the evolution of sex, multicellularity, and the Mesoproterozoic/Neoproterozoic radiation of eukaryotes. *Paleobiology* 26 (3): 386–404.
- The Bacterial Cytoskeleton. Shih YL, Rothfield L. Microbiol Mol Biol Rev. 2006 Sep;70(3):729-54.
- http://www.ncbi.nlm.nih.gov/sites/entrez?cmd=Retrieve&db=pubmed&dopt=Abstract&list_uids=169
- http://en.wikipedia.orghttp://en.wikipedia.org

Vocabulary

chloroplast The organelle of photosynthesis; captures light energy from the sun and uses it with water and carbon dioxide to make food (sugar) for the plant.

cilia (cilium) Made up of extensions of the cell membrane that contain microtubules; involved in movement.

cell wall A rigid layer that is found outside the cell membrane and surrounds the cell; provides structural support and protection.

cytoplasm The gel-like material within the cell that holds the organelles.

cytoskeleton A cellular "scaffolding" or "skeleton" that crisscrosses the cytoplasm; helps to maintain cell shape, it holds organelles in place, and for some cells, it enables cell movement.

endoplasmic reticulum (ER) A network of phospholipid membranes that form hollow tubes, flattened sheets, and round sacs; involved in transport of molecules, such as proteins, and the synthesis of proteins and lipids.

flagella (flagellum) Long, thin structures that stick out from the cell membrane; help single-celled organisms move or swim towards food.

Fluid Mosaic Model Model of the structure of cell membranes; proposes that integral membrane proteins are embedded in the phospholipid bilayer; some of these proteins extend all the way through the bilayer, and some only partially across it; also proposes that the membrane behaves like a fluid, rather than a solid.

gene A short segment of DNA that contains information to encode an RNA molecule or a protein strand.

gene expression The process by which the information in a gene is "decoded" by various cell molecules to produce a functional gene product, such as a protein molecule or an RNA molecule.

Golgi apparatus A large organelle that is usually made up of five to eight cup-shaped, membrane-covered discs called cisternae; modifies, sorts, and packages different substances for secretion out of the cell, or for use within the cell.

integral membrane proteins Proteins that are permanently embedded within the plasma membrane; involved in channeling or transporting molecules across the membrane or acting as cell receptors.

intermediate filaments Filaments that organize the inside structure of the cell by holding organelles and providing strength.

lipid bilayer A double layer of closely-packed lipid molecules; the cell membrane is a phospholipid bilayer.

lysosome A vesicle that contains powerful digestive enzymes.

membrane protein A protein molecule that is attached to, or associated with the membrane of a cell or an organelle.

microfilament Filament made of two thin actin chains that are twisted around one another; organizes cell shape; positions organelles in cytoplasm; involved in cell-to-cell and cell-to-matrix junctions.

microtubules Hollow cylinders that make up the thickest of the cytoskeleton structures; made of the protein tubulin, with two subunits, alpha and beta tubulin; involved in organelle and vesicle movement; form mitotic spindles during cell division; involved in cell motility (in cilia and flagella).

mitochondria (mitochondrion) Membrane-enclosed organelles that are found in most eukaryotic cells; called the "power plants" of the cell because they use energy from organic compounds to make ATP.

multicellular organisms Organisms that are made up of more than one type of cell; have specialized cells that are grouped together to carry out specialized functions.

nucleus The membrane-enclosed organelle found in most eukaryotic cells; contains the genetic material (DNA).

organ A group of tissues that has a specific function or group of functions.

organ system A group of organs that acts together to carry out complex related functions, with each organ focusing on a part of the task.

peripheral membrane proteins Proteins that are only temporarily associated with the membrane; can be easily removed, which allows them to be involved in cell signaling.

peroxisomes Vesicles that use oxygen to break down toxic substances in the cell.

phospholipid A lipid made up of up of a polar, phosphorus-containing head, and two long fatty acid, non-polar "tails." The head of the molecule is hydrophilic (water-loving), and the tail is hydrophobic (water-fearing).

plasma membrane Phospholipid bilayer that separates the internal environment of the cell from the outside environment.

ribosomes Organelles made of protein and ribosomal RNA (rRNA); where protein synthesis occurs.

selective permeability The ability to allow only certain molecules in or out of the cell; characteristic of the cell membrane; also called the cell membrane.

spontaneous generation The belief that living organisms grow directly from decaying organic substances.

tissue A group of connected cells that has a similar function within an organism.

transport vesicle A vesicle that is able to move molecules between locations inside the cell.

vacuole Membrane-bound organelles that can have secretory, excretory, and storage functions; plant cells have a large central vacuole.

vesicle A small, spherical compartment that is separated from the cytosol by at least one lipid bilayer.

New Points to Consider

- How do you think small molecules, or even water, get through the cell membrane?
- Is it possible that proteins help in this transport process?
- What type of proteins would help with transport?