Unit 4
Cells

South Dakota Science Standards

9-12.L.1.1 Students are able to relate cellular functions and processes to specialized structures within cells.

9-12.S.1.2 Students are able to evaluate and describe the impact of scientific discoveries on historical events and social, economic, and ethical issues.

9-12.N.2.2 Students are able to practice save and effective laboratory techniques.

Prefix or Suffix	Definition
chloro-	green
cyto-	cell
endo-	within
exo-	outside of
hyper-	above, over
hypo-	below, under
iso-	equal
-osis	condition of; disease
-plast	organized living material

<u>Top Vocabulary Terms</u>

1. **Cell**
2. **Cell membrane**
3. **Nucleus**
4. **Ribosome**
5. **Mitochondria**
6. **Prokaryote**
7. **Eukaryote**
8. **Osmosis**

I. Introduction to 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.

By the end of this unit, you should be able to discuss the importance of microscopes in the discovery of cells, summarize what the cell theory proposes, identify the limitations on cell size, identify the three parts common to all cells, and compare prokaryotic and eukaryotic cells.

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.

During the 1670s, the Dutch tradesman Antony van Leeuwenhoek 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. 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.

What is the definition of a cell?

What two scientists were instrumental in designing and introducing microscopes to the world?

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 19th 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.

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 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.

What does the term resolution mean?

What type of microscope uses a beam of electrons to see molecules?

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.***
- ***Under current condition, 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.

What three things does the cell theory state?

Diversity of Cells

Introduction

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. 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.

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.

What are two benefits of cells being so small in size?

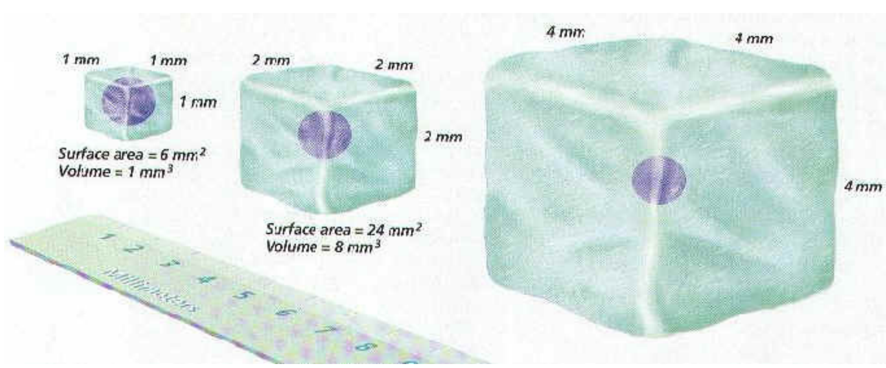


Figure 1: *This picture shows the surface area and volumes of three different sized cubes. The circle in the middle represents the cell nucleus.*

Cell Shape

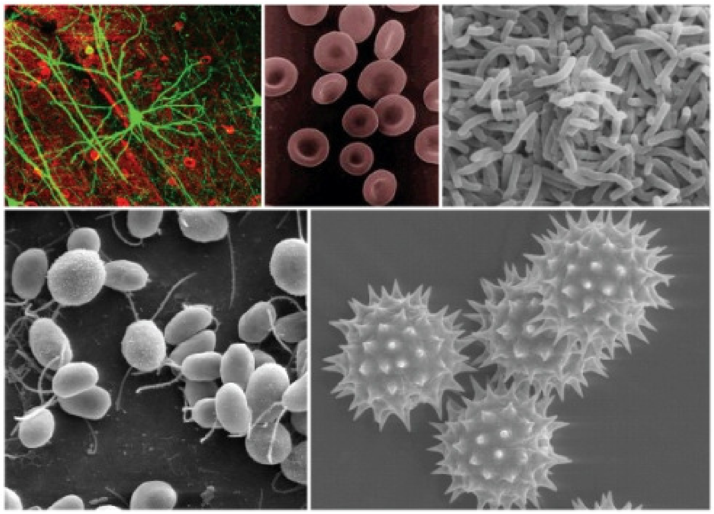


Figure 2: *Cells come in very different shapes. Left to right, top row: Long, thin nerve cells; biconcave red blood cells; curved-rod shaped bacteria. Left to right, bottom row: oval, flagellated algae and round, spiky pollen grains are just a sample of the many shapes.*

The 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 above 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.

How does cell shape relate to cell function?

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)

The **cell (plasma) 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 cytoplasm 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.

What are the four main parts to a cell?

Two Types of Cells

There are two cell types: prokaryotes and eukaryotes. **Prokaryotes** are usually single-celled, smaller than eukaryotic cells, and do not contain a nucleus or membrane-bound organelles. **Eukaryotes** contain a nucleus, membrane-bound organelles, and are usually larger because they are found in multicellular organisms. However, there are some single-celled eukaryotes that do exist in the world.

Prokaryotic Cells

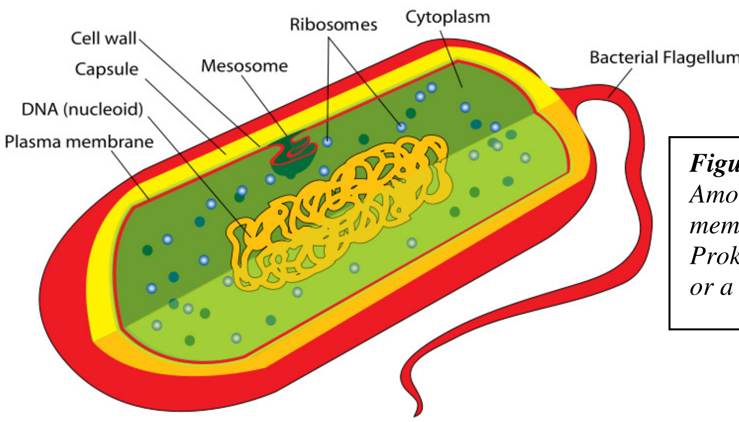


Figure 3: *Diagram of a typical prokaryotic cell. Among other things, prokaryotic cells have a plasma membrane, cytoplasm, ribosomes, and DNA. Prokaryotes do not have membrane-bound organelles or a cell nucleus.*

The bacterium in figure above 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 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.

What are two characteristics of a prokaryotic cell?

Eukaryotic Cells

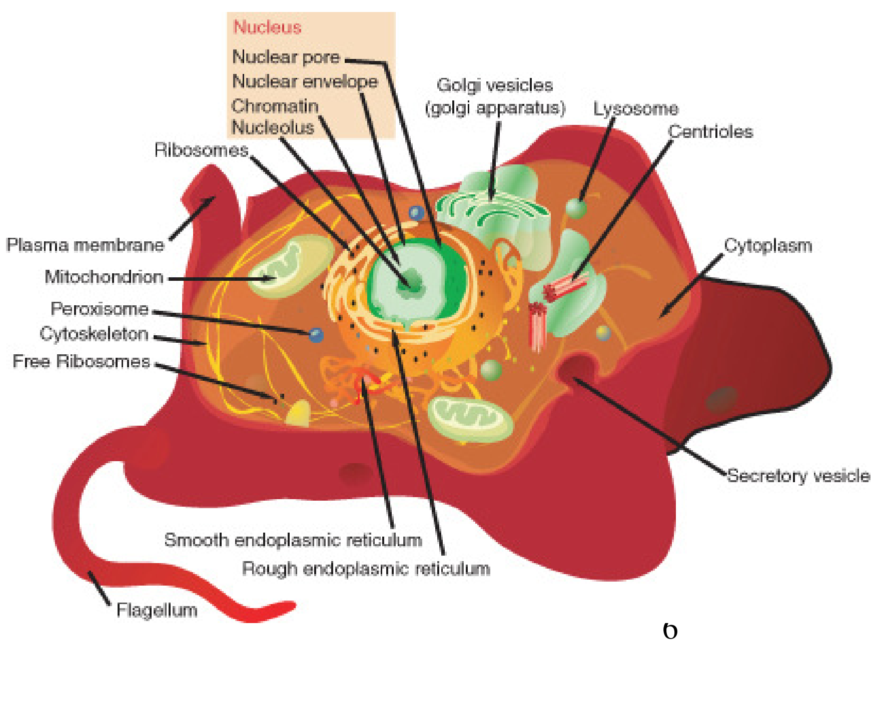


Figure 4: *A eukaryotic cell, represented here by a model animal cell is much more complex than a prokaryotic cell. Eukaryotic cells contain many organelles that do specific jobs. No single eukaryotic cell has all the organelles shown here, and this model shows all eukaryotic organelles.*

A eukaryote is an organism whose cells are organized into complex structures by internal membranes and a cytoskeleton, as shown in **Figure 4**. 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 listed in the table below. Eukaryotic cells may or may not have a cell wall. Plant cells generally have cell walls, while animal cells do not.

Structural Differences Between Prokaryotic Cells and Eukaryotic Cells

Presence of:	Prokaryote	Eukaryote
Cell (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 animal cells)
Average diameter	0.4 to 10 µm	1 to 100 µm

What are two differences between eukaryotic cells and prokaryotic cells?

What four things do both eukaryotes and prokaryotes both contain?

II. Cell Structures

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.

Cell (Plasma) Membrane

The cell (plasma) 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 **semipermeability**. These semipermeable membranes regulate the cell's interactions between the internal cytoplasm and the external surroundings. Proteins that are associated with the cell membrane determine which molecules can pass through the membrane. The cell membrane also acts as the attachment point for both the intracellular cytoskeleton and, if present, the cell wall.

The cell 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 cell membrane contains many different biological molecules, mostly lipids and proteins. These lipids and proteins are involved in many cellular processes.

What does the term semipermeable mean?

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 5**.

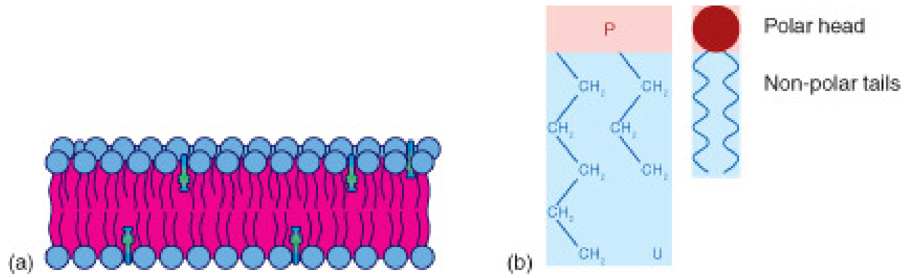


Figure 5: *The hydrophobic fatty acids point towards the middle of the plasma membrane and the hydrophilic heads point outwards. The membrane is stabilized by cholesterol molecules. This self-organization of phospholipids results in a semipermeable membrane which allows only certain molecules in or out of the cell.*

What is a phospholipid bilayer?

What does the term hydrophilic mean? Hydrophobic?

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. Their model 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 cell 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 and helps to maintain pressure within the cell.

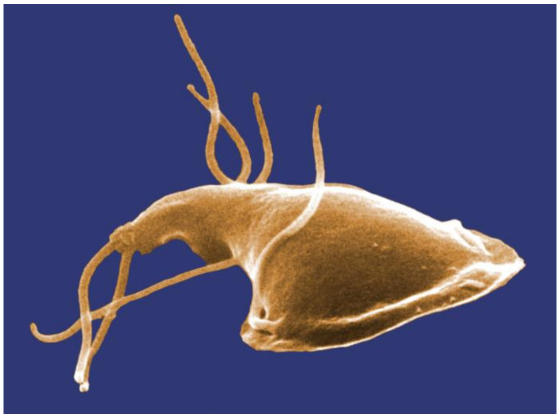
What is the main difference between cytoplasm and cytosol?

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. Two main kinds of cytoskeleton fibers are microtubules and microfilaments.

What is the cytoskeleton?

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 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.

Figure 6 *– This scanning electron micrograph shows characteristic flagella on the surface of a Giardia protozoan commonly found in a rat's intestine.*

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 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, in humans, the respiratory system is made up of mucus-secreting cells that line the trachea and bronchi. Ciliated cells 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 then swallowed and digested.

What two structures aide in movement of a cell?

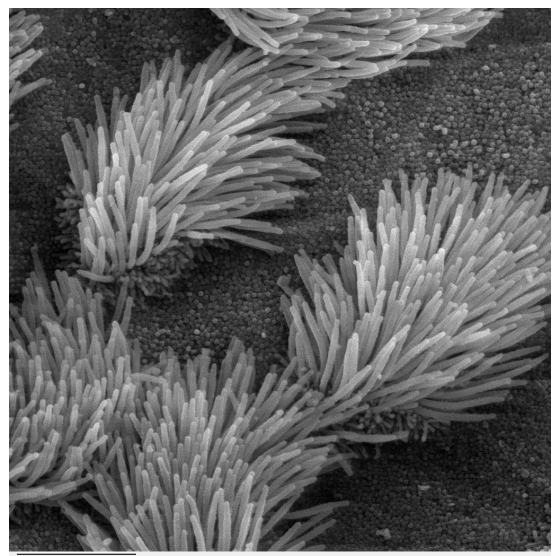


Figure 7 *– This scanning electron microscope image shows cilia lining the trachea.*

The Nucleus

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. 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.

Where in a cell is genetic information stored?

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** which 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. After being made in the nucleolus, ribosomes are exported to the cytoplasm where they direct protein synthesis.

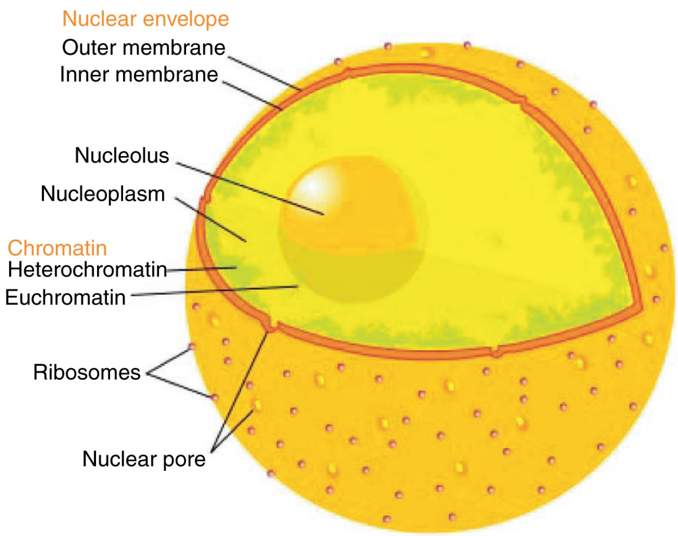


***Figure 8** – The eukaryotic cell nucleus. Visible in this diagram are the ribosome-studded double membranes of the nuclear envelope, the DNA (as chromatin), and the nucleolus.*

What structure protects the nucleus and its genetic material?

What structure in the nucleus helps with ribosome production?

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 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. 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.

What is the function of mitochondria?

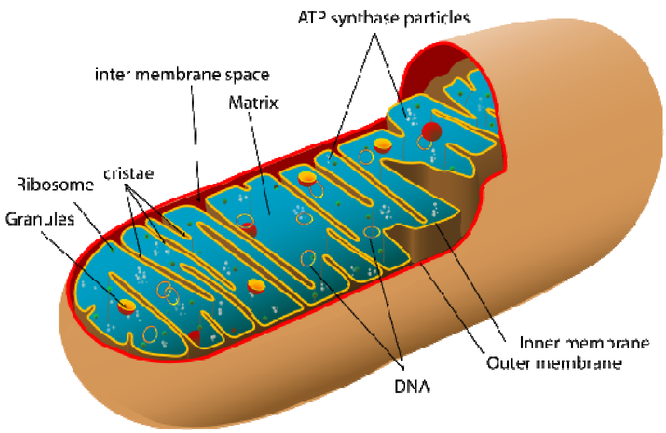


Figure 9 – *A typical mitochondrion consisting of an inner and outer membrane, ribosomes, and its own DNA.*

Endoplasmic Reticulum

The **endoplasmic reticulum (ER)** is a network of phospholipid membranes that form hollow tubes, flattened sheets, and round sacs. 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. Smooth endoplasmic reticulum and RER form an interconnected network.

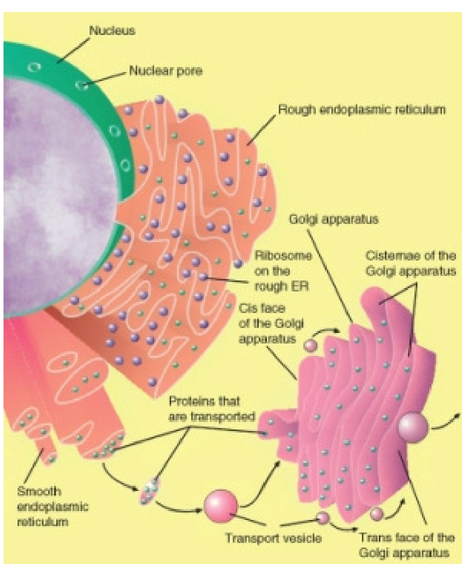


Figure 10 *–Image of a nucleus, endoplasmic reticulum and Golgi apparatus working together. The process of secretion from endoplasmic reticulum to the Golgi apparatus is shown.*

What are two functions of the endoplasmic reticulum in general?

What are the two types of endoplasmic reticulum?

Golgi Apparatus

The **Golgi apparatus** modifies, sorts, and packages different substances for secretion out of the cell, or for use within 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.

What is the function of the Golgi apparatus?

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. 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. They are common in liver and kidney cells that break down harmful substances.

What are the three main types of vesicles?

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.

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 which often store excess water.

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 has many functions. Aside from storage, the main role of the vacuole is to maintain turgor pressure against the cell wall. Often times, 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.

What is the function of a vacuole?

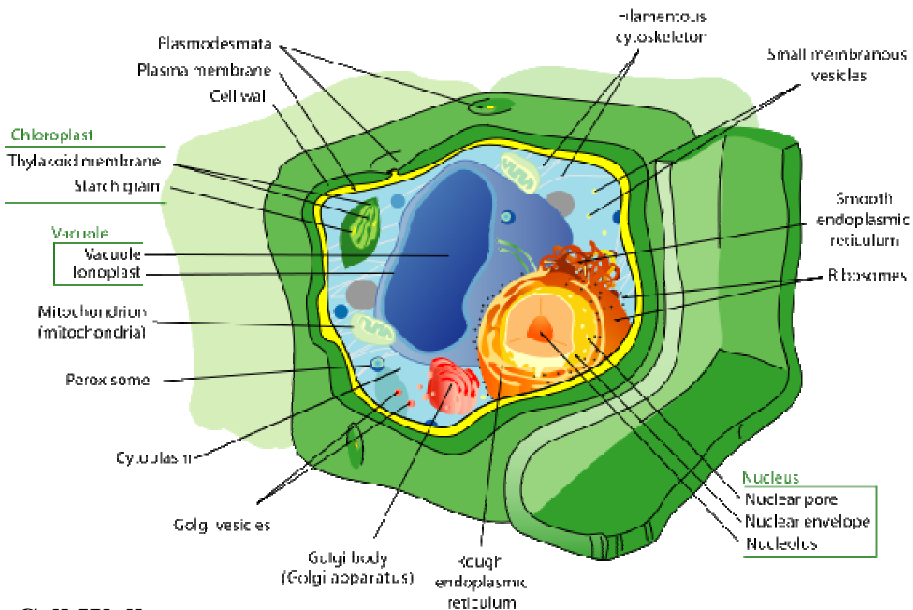


Figure 11 – Typical plant cell with most common structures labeled.

Cell Wall

A **cell wall** is a rigid layer that is found outside the cell membrane and surrounds the cell. The cell wall contains cellulose, protein, and a few other polysaccharides as well. 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.

What is the purpose of a cell wall?

Chloroplasts

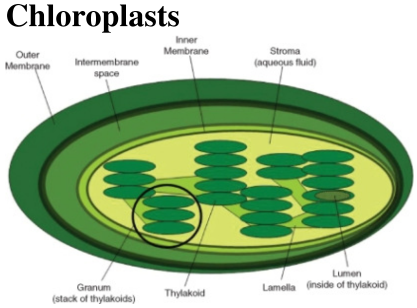


Figure 12 *– The internal structure of a chloroplast, with granal stacks of thylakoids circles.*

Chloroplasts are the organelles of photosynthesis. They are found in all plant cells and some protists. Chloroplasts capture light energy from the sun and use it with water and carbon dioxide to produce sugars for food.

What is the function of a chloroplast?

What three structures are only found in plant cells?

Cell Structure Review

Organelle	Function
	Allows certain molecules into and out of the cell; semipermeable
Nucleus	
	Gel-like material within a cell that holds the oranelles
Nucleolus	
	Double membrane of the nucleus that encloses and protects the genetic material
Mitochondria	
	A network of membranes that transports and synthesizes proteins
Vacuole	
	Rigid layer outside the cell membrane; provides support and protection
Chloroplast	

III. Cell Transport Mechanisms

Introduction

Probably the most important feature of a cell's phospholipid membranes is that they are semipermeable. A membrane that is **semipermeable** has control over what molecules or ions can enter or leave the cell, as shown in the figure below. The permeability of a membrane is dependent on the organization and characteristics of the membrane lipids and proteins. In this way, cell membranes help maintain a state of homeostasis within cells so that an organism can stay alive and healthy.

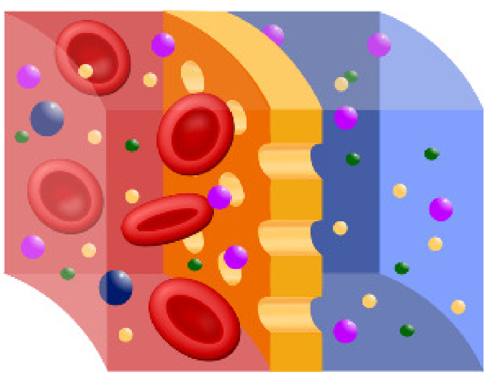


Figure 13 *– A semipermeable membrane allows certain molecules through, but not others.*

What does it mean for a membrane to be semipermeable?

Transport Across Membranes

The molecular make-up of the phospholipid bilayer limits the types of molecules that can pass through it. For example, hydrophobic (water-hating) molecules, such as carbon dioxide (CO_2) and oxygen (O_2), can easily pass through the lipid bilayer, but ions such as calcium (Ca^{2+}) and polar molecules such as water (H_2O) cannot easily pass through. The hydrophobic interior of the phospholipid does not allow ions or polar molecules through because they are hydrophilic, or water loving. In addition, large molecules such as sugars and proteins are too big to pass through the bilayer. Transport proteins within the membrane allow these molecules to cross the membrane into or out of the cell. This way, polar molecules avoid contact with the non-polar interior of the membrane, and large molecules are moved through large pores.

Every cell is contained within a membrane punctuated with transport proteins that act as channels or pumps to let in or force out certain molecules. The purpose of the transport proteins is to protect the cell's internal environment and to keep its balance of salts, nutrients, and proteins within a range that keeps the cell and the organism alive.

There are two main ways that molecules can pass through a phospholipid membrane. The first way requires no energy input by the cell and is called passive transport. The second way requires that the cell uses energy to pull in or pump out certain molecules and ions and is called active transport. Active transport often involves the use of vesicles, in which large molecules are moved across the membrane in bubble-like sacks that are made from pieces of the membrane.

What are the two main ways that molecules can pass through the cell membrane?

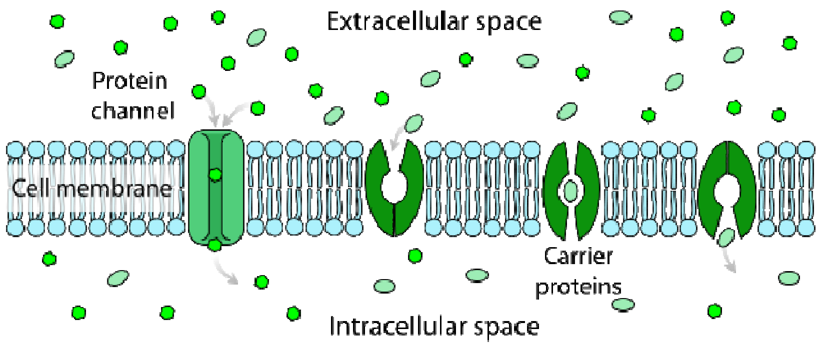


Figure 14 *– This picture shows protein channels embedded within the lipid bilayer. These channels facilitate the movement of melcules across the membrane. In some cases, molecules pass freely through, while in other cases, the protein has to change shape to allow the molecule through.*

Passive Transport

Passive transport is a way that small molecules or ions move across the cell membrane without input of energy by the cell. The three main kinds of passive transport are diffusion, osmosis, and facilitated diffusion.

Diffusion

Diffusion is the movement of molecules from an area of high concentration of the molecules to an area with a lower concentration. The difference in the concentrations of the molecules in the two areas is called the **concentration gradient**. Diffusion will continue until this gradient has been eliminated. Since diffusion moves materials from an area of higher concentration to the lower, it is described as moving solutes "down the concentration gradient." The end result of diffusion is an equal concentration, or **equilibrium**, of molecules on both sides of the membrane. If a molecule can pass freely through a cell membrane, it will cross the membrane by diffusion (**Figure 15**).

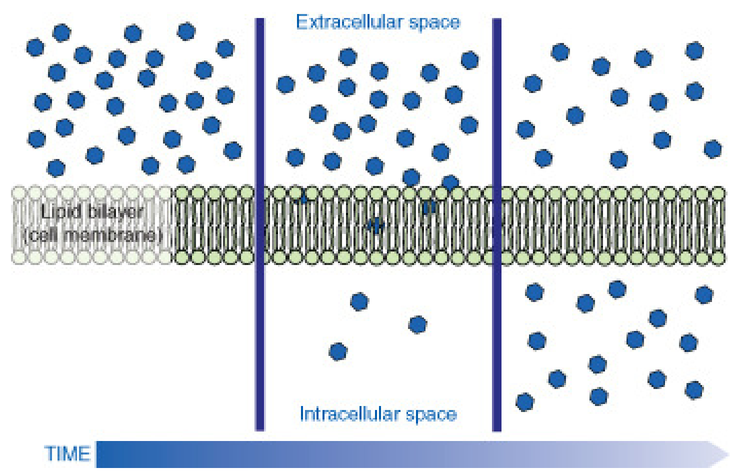


Figure 15 *– Molecules move from an area of high concentration to an area of lower concentration until equilibrium is met. The molecules continue to cross the membrane at equilibrium, but at equal rates in both directions.*

Does diffusion require the use of energy?

Define "equilibrium."

Osmosis

Imagine you have a cup that has 100 ml water, and you add 15 g of table sugar to the water. The sugar dissolves and the mixture that is now in the cup is made up of a solute (the sugar), that is dissolved in the solvent (the water). The mixture of a solute in a solvent is called a solution.

Imagine now that you have a second cup with 100 ml of water, and you add 45 g of table sugar to the water. Just like the first cup, the sugar is the solute, and the water is the solvent. But now you have two mixtures of different solute concentrations. In comparing two solutions of unequal solute concentration, the solution with the higher solute concentration is **hypertonic**, and the solution with the lower concentration is **hypotonic**. Solutions of equal solute concentration are **isotonic**.

You now add the two solutions to a beaker that has been divided by a selectively permeable membrane. The pores in the membrane are too small for the sugar molecules to pass through, but are big enough for the water molecules to pass through. The hypertonic solution is on one side of the membrane and the hypotonic solution on the other. The hypertonic solution has a lower water concentration than the hypotonic solution, so a concentration gradient of water now exists across the membrane. Water molecules will move from the side of higher water concentration to the side of lower concentration until both solutions are isotonic.

Osmosis is the diffusion of water molecules across a selectively permeable membrane from an area of higher concentration to an area of lower concentration. Water moves into and out of cells by osmosis. If a cell is in a hypertonic solution, the solution has a lower water concentration than the cell cytosol does, and water moves out of the cell until both solutions are isotonic. Cells placed in a hypotonic solution will take in water across their membrane until both the external solution and the cytosol are isotonic.

A cell that does not have a rigid cell wall (such as a red blood cell), will swell and lyse (burst) when placed in a hypotonic solution. Cells with a cell wall will swell when placed in a hypotonic solution, but once the cell is turgid (firm), the tough cell wall prevents any more water from entering the cell. When placed in a hypertonic solution, a cell without a cell wall will lose water to the environment, shrivel, and probably die. In a hypertonic solution, a cell with a cell wall will lose water too. The plasma membrane pulls away from the cell wall as it shrivels. Animal cells tend to do best in an isotonic environment, plant cells tend to do best in a hypotonic environment. This is demonstrated in the figure below.

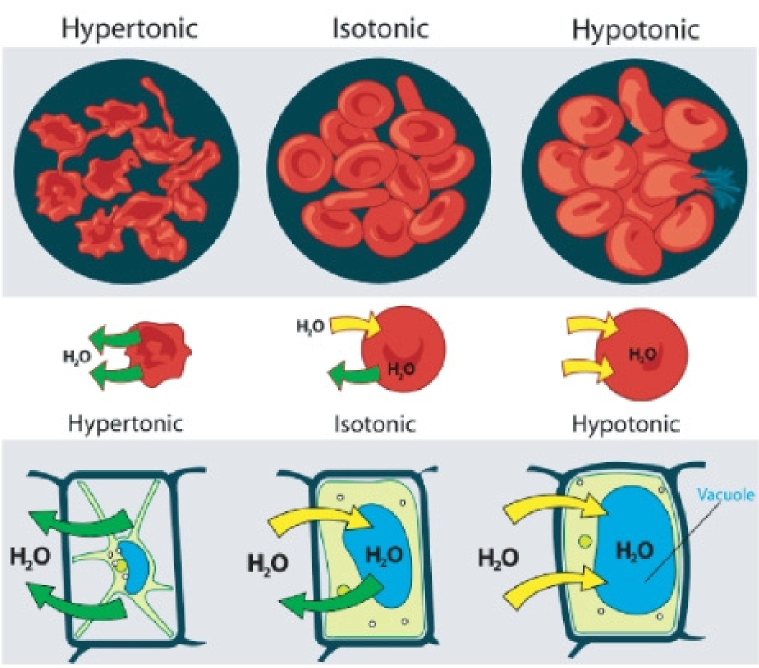


Figure 16 *– Unless an animal cell (such as the red blood cell in the top panel) has an adaptation that allows it to alter the osmotic uptake of water, it will lose too much water and shrivel up in a hypertonic environment. If placed in a hypotonic solution, water molecules will enter the cell causing it to swell and burst. Plant cells (bottom panel) tend to do best in a hypotonic environment.*

When water moves into a cell by osmosis, osmotic pressure may build up inside the cell. If a cell has a cell wall, the wall helps maintain the cell's water balance. Osmotic pressure is the main cause of support in many plants. When a plant cell is in a hypotonic environment, the osmotic entry of water raises the turgor pressure exerted against the cell wall until the pressure prevents more water from coming into the cell. At this point the plant cell is turgid.

The action of osmosis can be very harmful to organisms, especially ones without cell walls. For example, if a saltwater fish (whose cells are isotonic with seawater), is placed in fresh water, its cells will take on excess water, lyse, and the fish will die. Another example of a harmful osmotic effect is the use of table salt to kill slugs and snails.

Osmosis involves the movement of what across the cell membrane?

What three types of solutions can exist when discussing osmosis?

Facilitated Diffusion

Facilitated diffusion is the diffusion of solutes through transport proteins in the plasma membrane. Facilitated diffusion is a type of passive transport. Even though facilitated diffusion involves transport proteins, it is still passive transport because the solute is moving down the concentration gradient.

As was mentioned earlier, small nonpolar molecules can easily diffuse across the cell membrane. However, due to the hydrophobic nature of the lipids that make up cell membranes, polar molecules (such as water) and ions cannot do so. Instead, they diffuse across the membrane through transport proteins. A **transport protein** completely spans the membrane, and allows certain molecules or ions to diffuse across the membrane.

Why does facilitated diffusion not require energy, even though it uses a transport protein?

What are the three types of passive transport?

Active Transport

In contrast to facilitated diffusion, which does not require energy and carries molecules or ions down a concentration gradient, active transport pumps molecules and ions against a concentration gradient. Sometimes an organism needs to transport something against a concentration gradient. The only way this can be done is through active transport which uses energy (ATP) that is produced by cellular respiration. In active transport, the particles move across a cell membrane from a lower concentration to a higher concentration. **Active transport** is the energy-requiring process of pumping molecules and ions across membranes "uphill" against a gradient.

- The active transport of small molecules or ions across a cell membrane is generally carried out by transport proteins that are found in the membrane.

- Larger molecules such as starch can also be actively transported across the cell membrane by processes called endocytosis and exocytosis (discussed later).

What does active transport require that passive transport does not?

Sodium-Potassium Pump

Carrier proteins can work with a concentration gradient (passive transport), but some carrier proteins can move solutes against the concentration gradient (from high concentration to low), with energy input from ATP. As in other types of cellular activities, ATP supplies the energy for most active transport. One way ATP powers active transport is by transferring a phosphate group directly to a carrier protein. This may cause the carrier protein to change its shape, which moves the molecule or ion to the other side of the membrane. An example of this type of active transport system, as shown in the figure below, is the **sodium-potassium pump,** which exchanges sodium ions for potassium ions across the plasma membrane of animal cells.

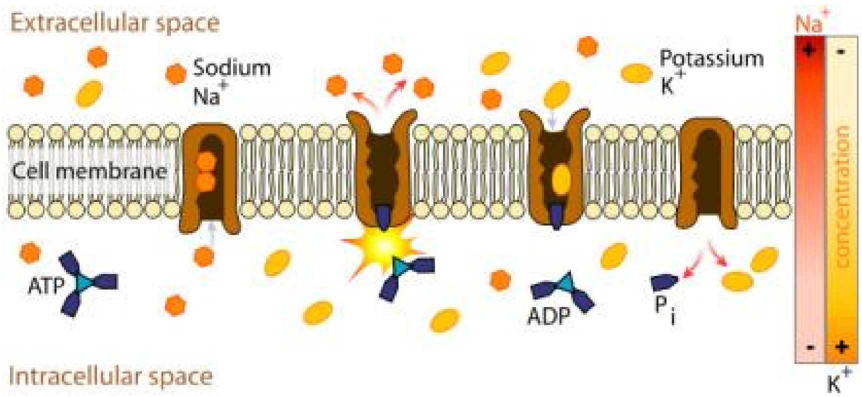


Figure 17 *– The sodium-potassium pump system moves sodium and potassium ions against large concentration gradients. It moves two potassium ions into the cell where potassium levels are high, and pumps three sodium ions out of the cell and into the extracellular fluid.*

What are two functions of the sodium-potassium pump?

Vesicles and Active Transport

Some molecules or particles are just too large to pass through the cell membrane or to move through a transport protein. So cells use two other methods to move these macromolecules (large molecules) into or out of the cell. Vesicles or other bodies in the cytoplasm move macromolecules or large particles across the cell membrane. There are two types of vesicle transport, endocytosis and exocytosis.

Endocytosis and Exocytosis

Endocytosis is the process of capturing a substance or particle from outside the cell by engulfing it with the cell membrane. The membrane folds over the substance and it becomes completely enclosed by the membrane. At this point a membrane-bound sac, or vesicle, pinches off and moves the substance into the cytosol.

Exocytosis describes the process of vesicles fusing with the cell membrane and releasing their contents to the outside of the cell. Exocytosis occurs when a cell produces substances for export, such as a protein, or when the cell is getting rid of a waste product or a toxin. Newly made membrane proteins and membrane lipids are moved on top the cell membrane by exocytosis.

How does exocytosis differ from endocytosis?

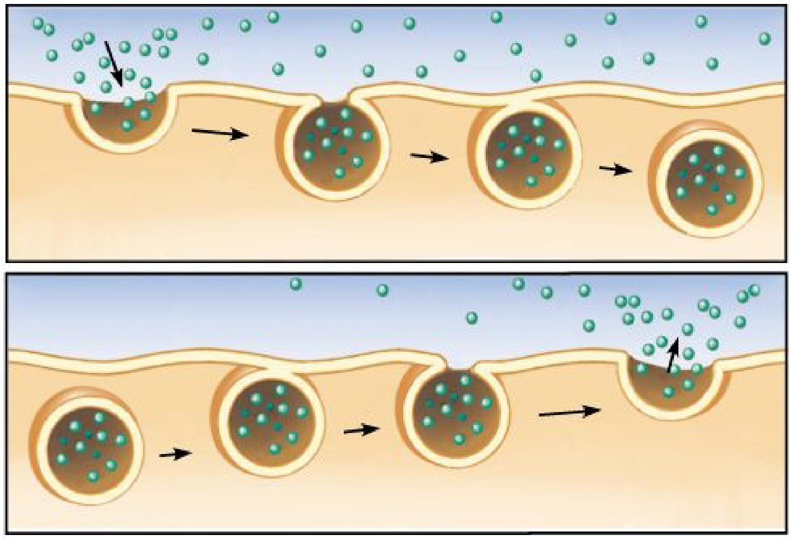


Figure 18 –

The top picture shows molecules entering a cell through the process of endocytosis. A vesicle engulfs the molecules and brings them into the cell.

The bottom picture shows molecules leaving a cell through the process of exocytosis. The vesicle fuses with the cell membrane and releases the molecule to the outside of the cell.

Homeostasis

Homeostasis refers to the balance, or equilibrium within the cell or a body. It is an organism's ability to keep a constant internal environment. Keeping a stable internal environment requires constant adjustments as conditions change inside and outside the cell. The adjusting of systems within a cell is called homeostatic regulation. Because the internal and external environments of a cell are constantly changing, adjustments must be made continuously to stay at or near the set point (the normal level or range). Homeostasis is a dynamic equilibrium rather than an unchanging state.

Define the term homeostasis.

Vocabulary

Active transport: The energy-requiring process of pumping molecules and ions across membranes against a concentration gradient.
Cell: The smallest unit of an organism that is still considered living; the basic unit that makes up every type of organism.
Cell (plasma) membrane: The physical boundary between the inside of the cell (intracellular) and its outside environment (extracellular). It acts almost like the "skin" of the cell.
Cell wall: Provides strength and protection for the cell; found around plant, fungal, and bacterial cells.
Centriole: Rod-like structures made of short microtubules; important in cellular division, where they arrange the mitotic spindles that pull the chromosome apart during mitosis.
Chloroplast: Green organelle that captures solar energy and stores the energy in sugars through the process of photosynthesis; chloroplasts are found only in cells that perform photosynthesis.
Cilia (cilium): Made up of extensions of the cell membrane that contain microtubules; involved in cell movement.
Concentration gradient: The difference in the concentrations of the molecules in two areas.
Cytoplasm: All the contents of the cell besides the nucleus, including the cytosol and the organelles.
Cytoskeleton: The internal scaffolding of the cell; maintains the cell shape and aids in moving the parts of the cell.
Cytosol: A fluid-like substance inside the cell; organelles are embedded in the cytosol.

Diffusion: The movement of molecules from an area of high concentration of the molecules to an area with a lower concentration.
DNA: Deoxyribonucleic acid, the genetic material; contains the genetic information needed for building structures such as proteins.
Endocytosis: The process of capturing a substance or particle from outside the cell by engulfing it with the cell membrane.
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; rough ER modifies proteins and smooth ER makes lipids.
Equilibrium: An equal concentration of molecules on both sides of the cell membrane.
Eukaryotes: Contain a nucleus, membrane-bound organelles, and are usually larger because they are found in multicellular organisms.
Exocytosis: The process of vesicles fusing with the cell membrane and releasing their contents to the outside of the cell.
Facilitated diffusion: The diffusion of solutes through transport proteins in the plasma membrane.
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 the membrane behaves like a fluid, rather than a solid.
Golgi apparatus: A large organelle that is usually made up of membrane-covered discs called cisternae; modifies, sorts, and packages proteins for secretion out of the cell, or for use within the cell.
Homeostasis: An organism's ability to keep a constant internal environment.
Hypertonic: The solution with the higher solute concentration.
Hypotonic: The solution with the lower solute concentration.
Isotonic: Solutions of equal solute concentration.
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.
Microfilaments: Part of the cytoskeleton; organize cell shape; position organelles in cytoplasm.
Microtubules: Hollow cylinders that make up the thickest of the cytoskeleton structures; involved in organelle and vesicle movement; form mitotic spindles during cell division; involved in cell motility (in cilia and flagella).
Mitochondria: The organelle in all eukaryotic cells that makes adenosine triphosphate (ATP), the "energy currency" of cells
Nuclear envelope: A double membrane that surrounds the nucleus; helps regulate the passage of molecules in and out of the nucleus.
Nucleolus: An organelle often found in the nucleus of cells; mainly involved in the assembly of ribosomes.
Nucleus: Membrane enclosed organelle in eukaryotic cells that contains the DNA; primary distinguishing feature between a eukaryotic and prokaryotic cell; the information center, containing instructions for making all the proteins in a cell, as well as how much of each one.
Organelle: Small structure wrapped in a membrane; found only in eukaryotic cells; mitochondria and vacuoles, for example.
Osmosis: The diffusion of water molecules across a selectively permeable membrane from an area of higher concentration to an area of lower concentration.
Passive transport: A way that small molecules or ions move across the cell membrane without input of energy by the cell.
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).
Phospholipid Bilayer: 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.
Plasma (cell) membrane: Surrounds the cell; made of a double layer of specialized lipids, known as phospholipids, with embedded proteins; regulates the movement of substances into and out of the cell; also called the cell membrane.
Prokaryotes: Usually single-celled, smaller than eukaryotic cells, and do not contain a nucleus or membrane-bound organelles.

Resolution: 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.
Ribosome: The cell structure on which proteins are made; not surrounded by a membrane; found in both prokaryotic and eukaryotic cells.
Rough endoplasmic reticulum (RER): The part of the ER with ribosomes attached; proteins can be modified in the rough ER before they are packed into vesicles for transport to the golgi apparatus.
Semi-permeable: Allowing only certain materials to pass through; characteristic of the cell membrane.
Smooth endoplasmic reticulum (SER): Part of the ER that does not have ribosomes attached; where lipids are synthesized.
Spontaneous generation: The belief that living organisms grow directly from decaying organic substances.
Sodium-potassium pump: A carrier protein that moves sodium and potassium ions against large concentration gradients, moves two potassium ions into the cell where potassium levels are high, and pumps three sodium ions out of the cell and into the extracellular fluid.
Stroma: The fluid within a chloroplast that contains DNA and ribosomes.
Thylakoid: The sub-organelles which are the site of photosynthesis in chloroplasts.
Transport protein: Completely spans the cell membrane and allows certain molecules or ions to diffuse across it.
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 which often stores excess water.
Vesicle: Small membrane-enclosed sac; transports proteins around a cell or out of a cell.

Works Cited

http://www.ck12.org
Figure 1 – http://www.biologyjunction.com/cell_size.htm
Figure 2 – http://commons.wikimedia.org/wiki/File:Animal_mitochondrion_diagram_en.svg.
Figure 3 – http://commons.wikimedia.org
Figure 4 – http://commons.wikimedia.org/wiki/Image:Rhoeo_Discolor_-_Plasmolysis.jpg.
Figure 5 – http://commons.wikimedia.org/wiki/File:Phospholipid_structure.png
Figure 6 – http://commons.wikimedia.org/wiki/File:Giardia_1.jpg
Figure 7 – http://commons.wikimedia.org/wiki/File:Bronchiolar_epithelium_3_-_SEM.jpg
Figure 8 –http://upload.wikimedia.org/wikipedia/commons/thumb/3/38/Diagram_human_cell_nucleus.svg/400px-Diagram_human_cell_nucleus.svg.png
Figure 9 – http ://commons.wikimedia.org/wiki/File:Animal_mitochondrion_diagram_en.svg
Figure 10 – http://commons.wikimedia.org/wiki/File:Elektronenmikroskop.jpg.
Figure 11 – http://commons.wikimedia.org/wiki/File:Plant_cell_structure_svg.svg
Figure 12 – http://en.wikipedia.org/wiki/Image:Turgor_pressure_on_plant_cells_diagram.svg
Figure 13 – http://commons.wikimedia.org/wiki/File:Cell_membrane_detailed_diagram_en.svg
Figure 14 - http://commons.wikimedia.org/wiki/File:Scheme_facilitated_diffusion_in_cell_membrane-en.svg
Figure 15 – http://commons.wikimedia.org/wiki/File: Scheme_facilitated_diffusion_in_cell_membrane-en.svg
Figure 16 – http://commons.wikimedia.org/wiki/File:Ribosome_structure.png
Figure 17 – http://commons.wikimedia.org/wiki/File:Scheme_sodium-potassium_pump-en.svg
Figure 18 – http://4.bp.blogspot.com/_rBYpndaJ_ak/TLZLaM4OCQI/AAAAAAAAARU/8iax7xfb0F4/s1600/Endocytosis+and+Exocytosis.jpg