

CELLS

So far, we have combined atoms to form compounds and molecules. Those molecules were then used to form macromolecules. From the macromolecules, we will form cells. This building process continues until we have an entire organism.

atoms → molecules/compounds → macromolecules → cells → tissues → organs → systems → organism

In order to understand cells, let's go back to the time of Galileo. Galileo studied the heavens with a device called the telescope. Although he did not invent the telescope, he used it in a systematic way to study the stars. The concept of a telescope is to view objects far away and make them appear very close. From that idea, it is not very far to think of viewing objects that are very small and making them appear large; thus the microscope.

The Dutch lens maker Anton von Leeuwenhoek (1632-1723) created the first microscope. Strangely, though he was a lens maker, his first microscope utilized the magnifying properties of water, not lenses (Water magnifies an object by 1/3.). Von Leeuwenhoek was the first person to see what we now know today as bacteria and as such, he is considered to be the father of microbiology.

For quite some time after Von Leeuwenhoek, the microscope was considered something of a parlor toy in the wealthier houses of Europe. People were entertained by looking at human hair, finger nail clippings, and other such mundane items. It was left to Robert Hooke (1635-1703) to use the microscope for scientific purposes. He looked at thinly sliced cork under the microscope and saw regular, repeating hexagonal shapes. As a beekeeper, Hooke was familiar with this view. Honeycombs were designed exactly the same way and since individual units of honeycombs were called cells, he coined the term "cell" for these units seen with cork. We thank Robert Hooke for creating the term "cell" in biology!



Later, Matthias Schleiden (1804-1881) a German botanist, began to look at plant tissue under the microscope. He saw the same regular, repeating pattern as Hooke and came to the conclusion that all plants are composed of basic units called cells.

Theodor Schwann (1810-1882) a German zoologist, began to look at animal tissue under the microscope. He saw the same thing in animals and said all animals are composed of basic units called cells.

Rudolf Virchow (1821-1902) a German biologist, observed cells arise from pre-existing cells.

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From Schleiden and Schwann's concept about plants and animals, and from Virchow's theory on cells arising from pre-existing cells, we derive the unified cell theory. The unified cell theory states:

1. all living things are composed of basic units called cells, and
2. cells arise from pre-existing cells.

Commonality of Cells

From studies of cells, it becomes obvious all cells have certain things in common, regardless of the type or form. All cells have:

1. a cell membrane (plasma membrane) – a boundary
2. protoplasm – the living contents of the cells
3. genetic material (at least in some stage of their life) – deoxyribonucleic acid (DNA).

Types of Cells

Regardless of common features, cells may be divided into two major categories: prokaryotic and eukaryotic.

Prokaryotic

The prefix *pro* means before. The root word is *karyote* (literally translated from the Greek as “nut”). Of course, the term in which we are interested is not “nut” but nucleus. Prokaryotic means before the nucleus. We are referring to cells which do not have membrane-bound organelles such as a nucleus, mitochondria, endoplasmic reticula, *etc.* These processes are carried out elsewhere in the cell. Examples of prokaryotic cells are bacteria and cyanobacteria (blue-green algae).

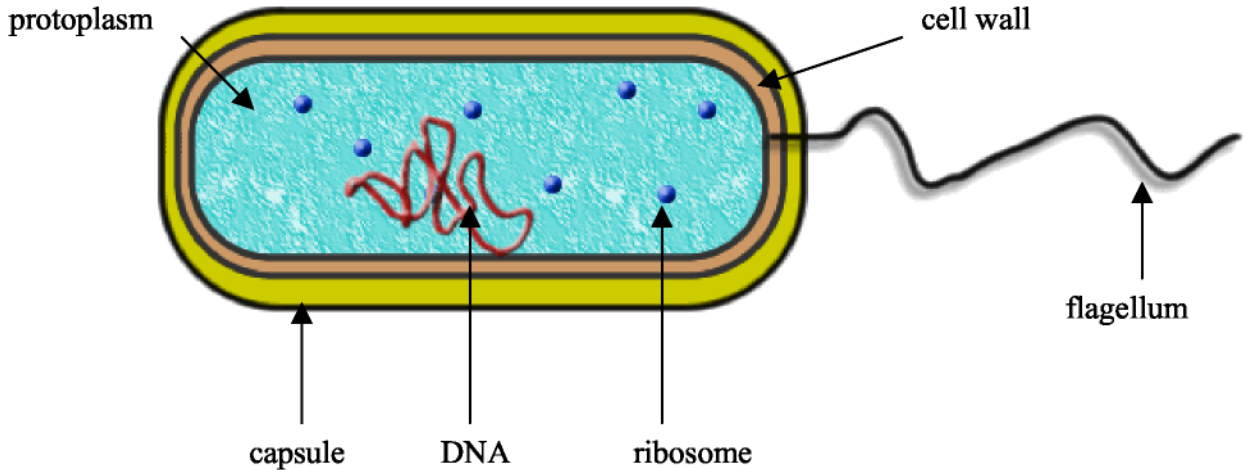
Eukaryotic

The prefix *eu* means true. Therefore, this type of cell has a true nucleus. More appropriately, it has membrane-bound organelles such as mitochondria, endoplasmic reticula, *etc.* These cells are represented by animals, plants, fungi, and single-celled or colonial creatures called Protistans.

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Prokaryotic Cells

Remember, all cells have a cell membrane. However, prokaryotic cells have a structure to the outside of the membrane, manufactured by that membrane, called the cell wall. The cell wall in prokaryotic cells is composed of a material called murein. Murein is actually amino acids linked together by sugar bonds. It is a fairly rigid, tough structure that protects the cell.



Inside the cell is the living contents – the protoplasm. As part of the protoplasm, small, dot-like structures called ribosomes are scattered throughout. Ribosomes are the sites of protein synthesis.

In addition to ribosomes, there is a single copy of deoxyribonucleic acid (DNA). DNA is the hereditary material of the cell. The DNA found in bacteria and cyanobacteria is unusual in several respects. The best way to discuss prokaryotic DNA is to compare it to eukaryotic DNA.

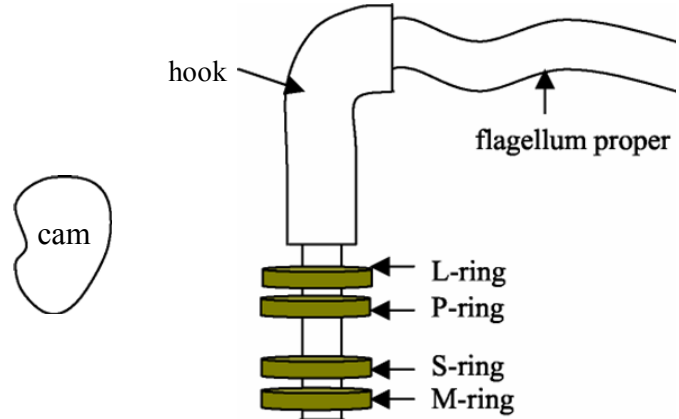
Trait	Prokaryotic	Eukaryotic
Copies	Single copy	Multiple copy (in humans, 46)
Structure	Circular	Linear (think chromosomes)
Composition	DNA and non-histone protein	DNA and histone proteins

Prokaryotic cells may have additional features but these are the basics. However, one other cell feature needs to be discussed – flagella. Flagella are long whip-like structures used in locomotion. Not all prokaryotic cells have flagella (and none have cilia), both those that do have flagella may have single or multiple flagella.

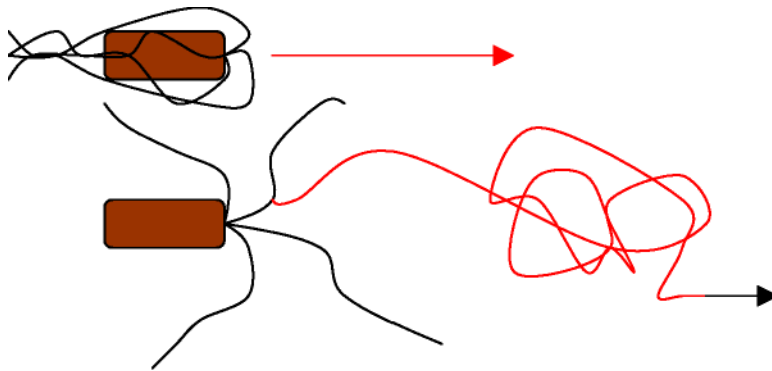
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Prokaryotic Flagella

Prokaryotic flagella are composed of special proteins called *flagellin*. Don't confuse the singular and plural forms of the word flagellum (flagella) with the protein flagellin. All prokaryotic flagella are composed of three units: (1) flagellum proper (2) hook (3) and a series of rings. The hook is very similar to a piece of pvc pipe called an elbow joint. The flagellum proper is simply the whip-like structure attached to one end of the hook. It's the rings that are more than a little interesting. There are 4 rings associated with many bacterial flagella. They are the "L", "P", "S", and "M" rings (in that order as you go down the shaft to which they are attached). The rings and shaft are embedded within the cell wall and cell membrane of the prokaryotic cell. The rings are not perfectly round. Instead, their appearance is very much similar to the cam attached to Nautilus© weight-lifting equipment. The cam is the part to which the chain is attached in the weight-lifting equipment. The shaft to which the rings are attached is called the cam shaft. The cams and shaft of the flagella work very much like the cams in the Wankel rotary engine.



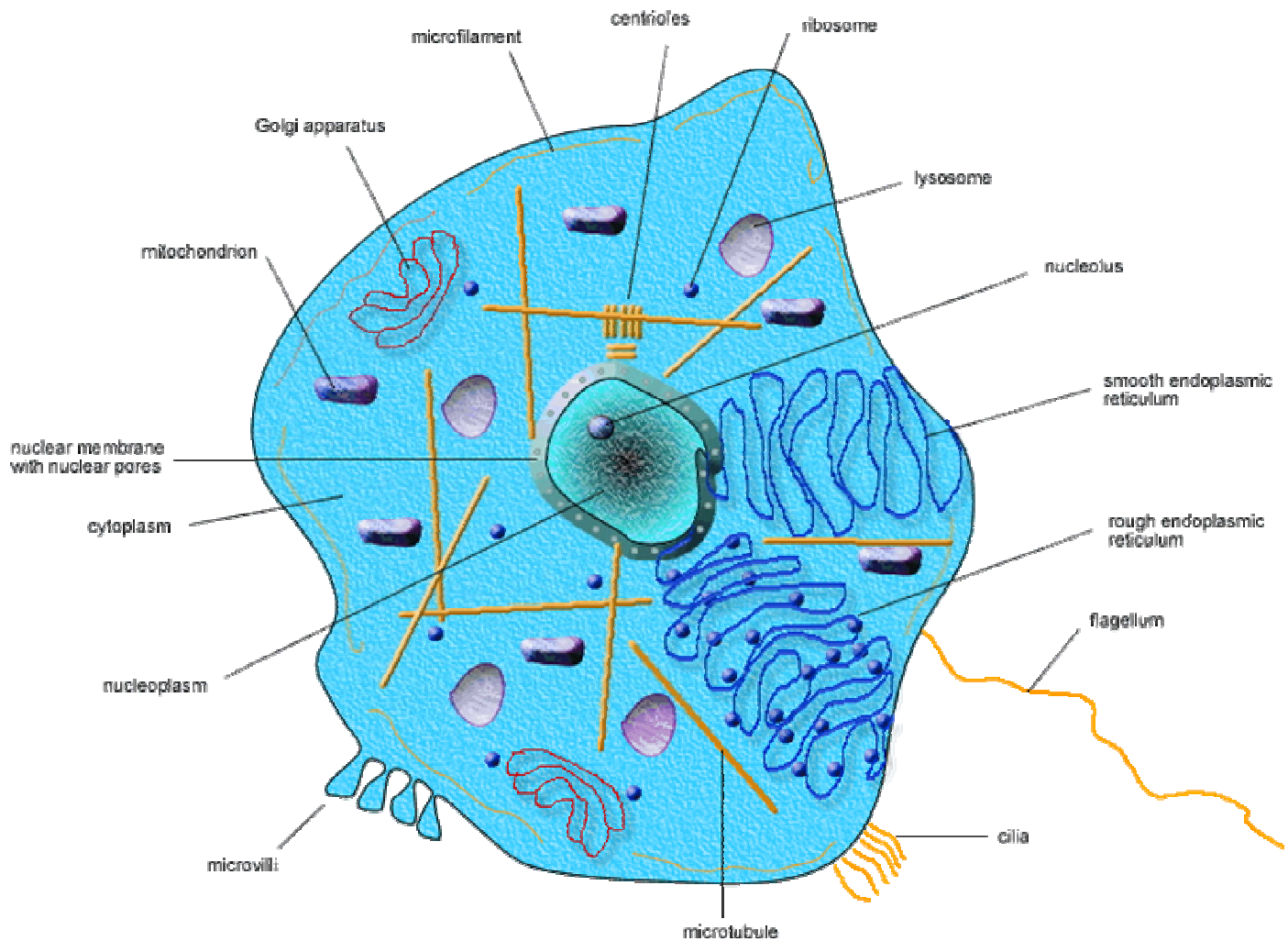
When the shaft rotates one direction (say clockwise), the flagella become intertwined and simply undulate in place. This causes the bacterium to move in somewhat of a straight line. However, when the shaft reverses its direction, the flagella become untangled and they move somewhat independently. This causes the bacterium to tumble and move erratically. The question is "why move erratically?" The answer is to (1) escape from predators and (2) erratic movements are better for finding food.



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Eukaryotic Cells, An Overview

First, eukaryotic cells are much larger than prokaryotic cells. In addition, it becomes immediately obvious there are membrane bound structures within the eukaryotic cell.



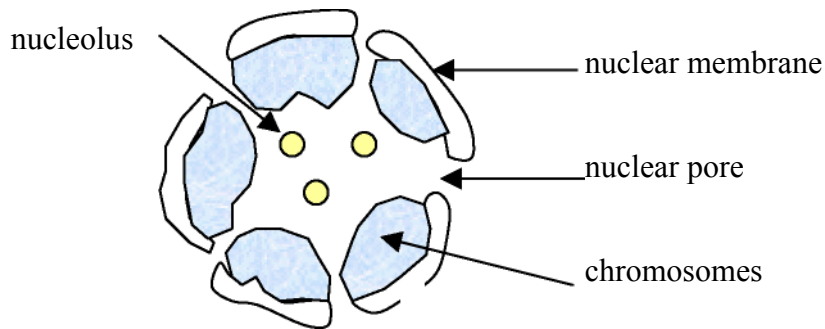
The Nucleus

The first membrane-bound feature which is obvious is the nuclear membrane surrounding the nucleus. The membrane is double-layered and is dotted with nuclear pores. Materials are able to move into and out of the nucleus through these pores. Inside the nucleus is a densely staining material referred to as chromatin. Chromatin is actually the chromosomes of the nucleus. In humans, there would be 46 chromosomes per nucleus. Chromosomes, remember, are composed of DNA and histone proteins. The term chromosome translates from the Greek as *chromos* = colored and *somos* = body, or colored bodies – reinforcing the idea that these structures have an affinity for certain dyes.

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Most of the nucleus is space. The chromosomes are pushed tightly up against the edge of the nuclear membrane. Inside the nucleus may be other dot-like structures which resemble tiny nuclei. These are the nucleoli, composed primarily of RNA. Be careful with singular and plural forms of these words.

Singular	Plural	Description
Nucleus	Nuclei	Brain of the cell; contains chromosomes and nucleoli
Nucleolus	Nucleoli	Small structures found inside the nucleus composed of RNA



Cytoplasm vs Protoplasm

Often you hear biologists use the term cytoplasm and protoplasm. These are two very different terms. Protoplasm was defined earlier as the living contents of the cell. Cytoplasm is defined as the region of protoplasm from the cell membrane to the nuclear membrane. In essence, by definition, prokaryotic cells don't have cytoplasm.

Endoplasmic Reticulum

Attached to and continuous with the nuclear membrane is the endoplasmic reticulum. The endoplasmic reticulum is a double-layered membrane (as is the nuclear membrane) which wanders through significant portions of the cytoplasm with channels spreading throughout. Much of the endoplasmic reticulum's interior is space. A space in biology is called a lumen. There are two types of endoplasmic reticula: (1) smooth and (2) rough.

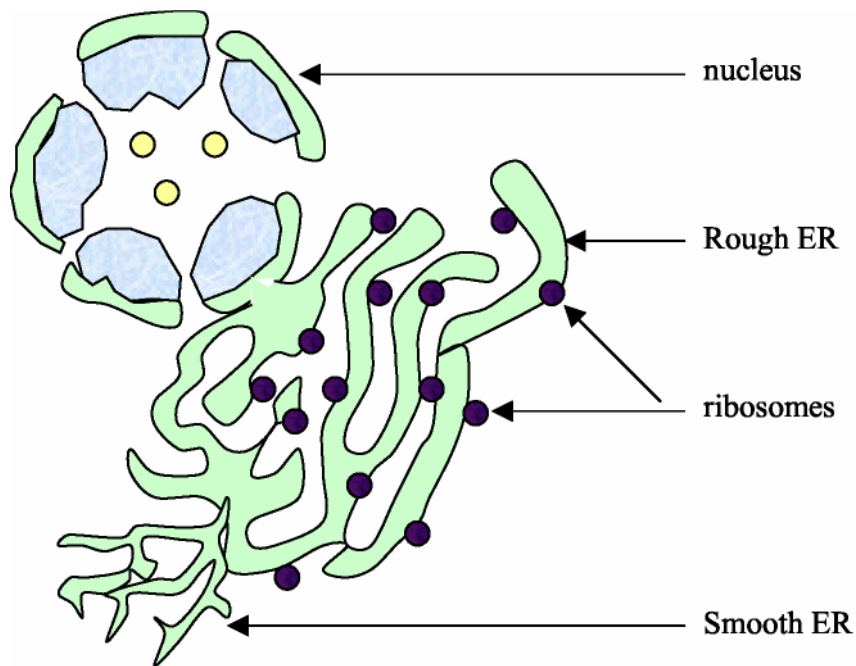
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Smooth ER

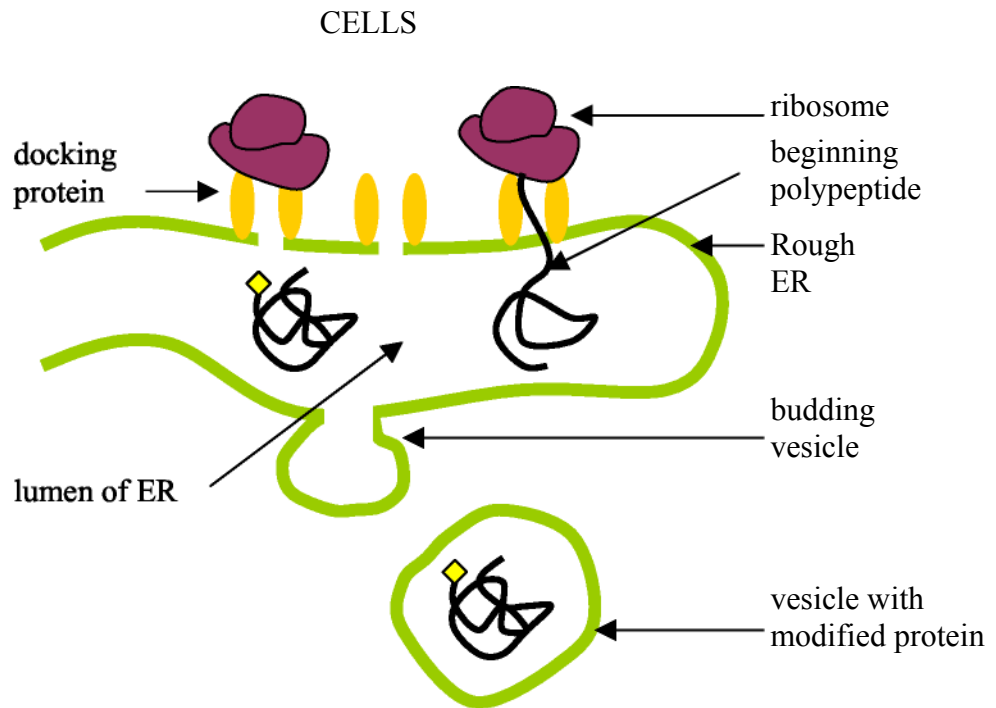
Smooth endoplasmic reticulum, when viewed under an electron microscope, has an even, smooth appearance. This type of endoplasmic reticulum is involved in the synthesis of lipids.

Rough ER

Rough ER, when viewed with an electron microscope, is rough in appearance. The texture is determined by tiny dot-like structures attached to the surface of the ER. These dot-like structures are the same structures seen in prokaryotic cells, called ribosomes. Just as ribosomes are the sites of protein synthesis in prokaryotic cells, the rough ER in eukaryotic cells is involved in the formation of proteins.



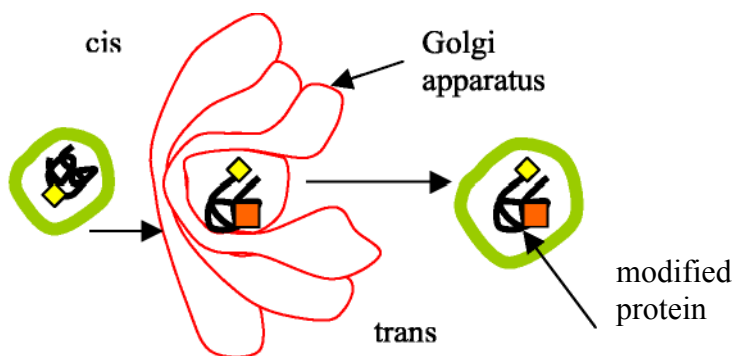
The rough ER has tiny openings in its surface. These openings are surrounded by a protein (called docking proteins). The docking proteins are the site of attachment of ribosomes. Ribosomes, while in the cytoplasm, begin to string together amino acids to begin the formation of a polypeptide. The first part of the polypeptide is called the signal sequence. The signal sequence recognizes the docking protein and allows the ribosome to dock to the surface of the ER. The ribosome continues the production of the polypeptide. As the polypeptide continues to increase in length, it is pushed into the lumen of the ER. Once deposited inside, the polypeptide automatically takes the conformation of protein due to hydrogen bonds and “R” group interactions. There the protein may be further modified. In some cases, the protein is cleaved into two or more pieces. In other cases, it may have sugars attached (glycoproteins) or fats (lipoproteins).



On the opposite side of the ER from the docking proteins, the ER begins to pouch outward to form a vesicle. The newly produced protein in the ER may be deposited in this growing bud. Eventually, the vesicle with protein in pinched off and discharged into the cytoplasm. From there, the vesicle travels to the Golgi apparatus.

Golgi Apparatus

The Golgi apparatus (named after Emilio Golgi, Italian biologist) is another set of double-layered membranes. Sometimes the Golgi seems to appear as a stack of membranes collapsed in on themselves. The Golgi has two surfaces: (1) the “cis” surface which faces the ER and (2) the “trans” surface which faces the cell membrane. The vesicle from the ER with the protein inside now fuses with the Golgi on the *cis* surface. The protein is dumped into the lumen of the Golgi. Inside the Golgi, the protein may be further modified by cleaving or adding materials. Once inside, the protein is sorted to a branch of the Golgi. From there it is dumped into a developing vesicle on the *trans* side of the Golgi and pinched off and sent to the location inside the cell for which it is needed.



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There are three major functions of the Golgi:

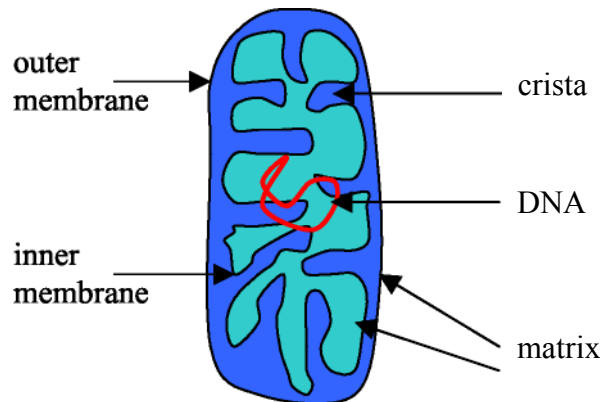
1. further modification of proteins
2. sorting of proteins, and
3. secretion of proteins.

The term secretion is significant. Make sure you understand the difference between “secretion” and “excretion”. These proteins are secreted.

The shocking thing about the above description is in a few paragraphs, something was explained which took biologists years of research to determine. What actually took place is an amazing set of events. First, cells are not in the habit of making proteins unless needed. The cell has to determine the need for a protein – let’s say one for the cell membrane. Once the need is recognized, the cell must make the protein and insert it in the membrane. However, the genetic blueprint for that protein is in the nucleus on a chromosome. If it is a human cell, there are 46 of these that must be scanned to determine the location of the gene for that particular protein. Once the gene is located, it must be interpreted to make the protein. That message must be sent from the nucleus to the ribosome. The ribosome makes the protein, the ER modifies it, packages it and sends it to the Golgi where it is further modified, sorted, and secreted. It is then inserted into the membrane. This process is stunningly fast. How quickly can a cell manufacture a protein? We don’t have instrumentation sensitive enough to make that determination. What we do have is instrumentation sensitive enough to determine the production of large amounts of proteins. So, let’s rephrase the question. How quickly can a cell manufacture measurable quantities of a protein? The answer is microseconds! Cells, are in essence, protein factories.

Mitochondria

Mitochondria are double-layered membranes typically with an oval shape (the shape can be highly varied, particularly in plant cells). Mitochondria are considered the energy packets of the cell. Think of them as batteries. The energy produced is in the form of ATP.



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The outer membrane of the mitochondria pretty much gives it shape. The inner membrane is thrown up into finger-like projections called lamellae (or lamella – singular) or cristae (or crista - singular). These lamellae (or cristae) protrude towards the interior. It is on the surface of the lamellae that ATP is produced. The inside of the mitochondrion is remarkably like protoplasm. This protoplasmic-like material is called the matrix.

There is one additional material associated with mitochondria. There is a single copy of circular DNA that contains non-histone proteins. Sound familiar? That is why Lynn Margulis states these are not mitochondria. Instead, she believes them to be prokaryotic cells living in a symbiotic relationship with a eukaryotic cell.

Symbiosis

There are various forms of symbiosis in biology. The term means “living together”. It’s the arrangement of living that is important. There are three primary means of symbiosis.

TERM	DEFINITION	EXAMPLE
Parasitism	Two organisms living together, one at the expense of the other	Tapeworms
Commensalism	Two organisms living together, one benefits, the other is neither helped nor harmed	The green alga <i>Ulothrix</i> found attached to the upper shell (carapace) of turtles
Mutualism	Two organisms living together, both benefit	Algae living in the polyps of coral

In essence, Margulis claims mitochondria are prokaryotic cells living in a *mutualistic* relationship with eukaryotic cells. The “bacterium” or mitochondrion provides ATP to the host. The host provides a place to live, food and water, *etc.*

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Lysosomes

Lysosomes are double-membrane bound structures with a round shape. They are the digestive packets of the cell. The word *lysis* means to loosen or break apart and *somos* means body. Literally translated, it means to loosen or break apart bodies.

Lysosomes fuse with food vacuoles in the cell. Once they fuse with the vacuole, the pH drops and digestive enzymes within the lysosome become activated.

In a remarkable event, some cells' lysosomes disperse their contents into the cell. This causes the cell to digest itself – in essence, commit suicide.

In one case, certain fungi auto-digest the cap of the fungus in order to provide a sticky medium for fungal spores. When flies land on this soupy spore mixture, the spores attach. The fly then carries the spores to a new location. It's the method the fungus reproduces itself to different locations.

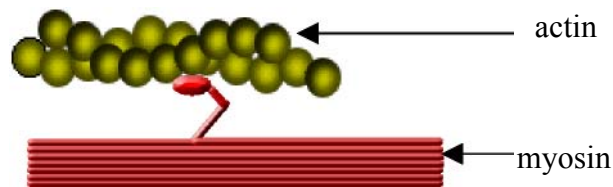
Peroxisomes

These are very similar to lysosomes with the exception of their function. Hydrogen peroxide is a natural bi-product of certain cell biochemical processes. Left to itself, hydrogen peroxide often decomposes into the hydroxide ion $[OH^-]$ and the superoxide radical $[O^-]$. Both are very dangerous and the superoxide radical has even been implicated as a carcinogen.

However, hydrogen peroxide (H_2O_2) in the presence of the enzyme peroxidase, is broken down into water and oxygen – two harmless substances. This reaction takes place in the peroxisome.

Microfilaments

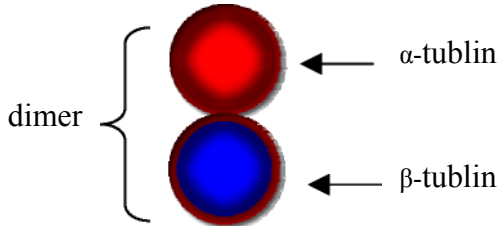
Microfilaments are concentrated just under the surface of the cell membrane. They are thread-like filaments composed of two proteins: actin and myosin (thin and thick, respectively). The microfilaments do two things: they contract or they relax their contractions.



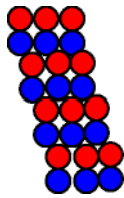
Microfilaments are like your muscles in that muscles can only contract and relax their contraction. The reason for the similarity is simple. Muscle cells are composed of actin and myosin.

Microtubules

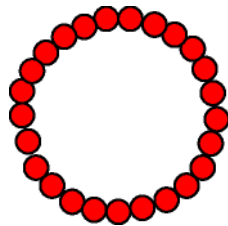
Microtubules are the internal skeleton of the cell. They are scattered throughout the cell and provide internal support. Think of them as steel reinforcing rods (rebar) in construction to which concrete is added. Rebar gives concrete additional support and strength. Microtubules are composed of the protein tubulin.



Tubulin is a dimer – meaning it is composed of two tertiary proteins: alpha tubulin and beta tubulin. These molecules are like two basket balls, one atop the other. However, a single tubulin protein will not form a microtubule. Instead, tubulin proteins align themselves to form a hollow cylinder – much like a soda straw.



Side view

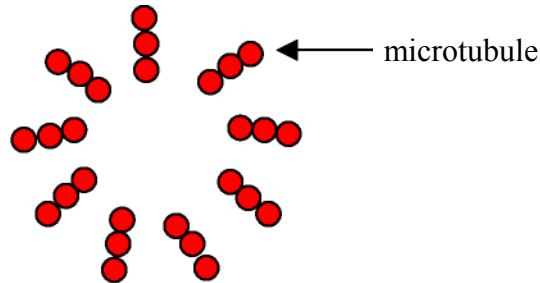


Top view

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Centrioles

Close to the nucleus are another set of rod-like structures called centrioles. There are two sets, one perpendicular to the other. Centrioles have a role in cell division. Centrioles are composed of microtubules. These are arranged with nine sets of three in a circle. Another set runs perpendicular to the first set.



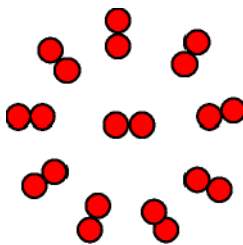
A discussion of centrioles will be deferred until we reach mitosis.

Microvilli

Sometimes, the cell membrane is not completely smooth and even. On some cells, the cell membrane is thrown up into finger-like projections called microvilli. Microvilli serve to increase the surface area of the cell membrane.

Cilia and Flagella

Often, eukaryotic cells are motile. To move, they may use either cilia (short, hair-like projections) or flagella (long, whip-like structures). These are different from the type seen in prokaryotic cells. These cilia and flagella are composed of microtubules, like centrioles. However, the arrangement is not 9 sets of 3 microtubules. Instead, eukaryotic cilia and flagella almost universally have 9 sets of 2 with 2 microtubules in the center. This is referred to as the 9+2 arrangement. There are only two known places, one in the animal kingdom and one in the plant kingdom that this formula varies.

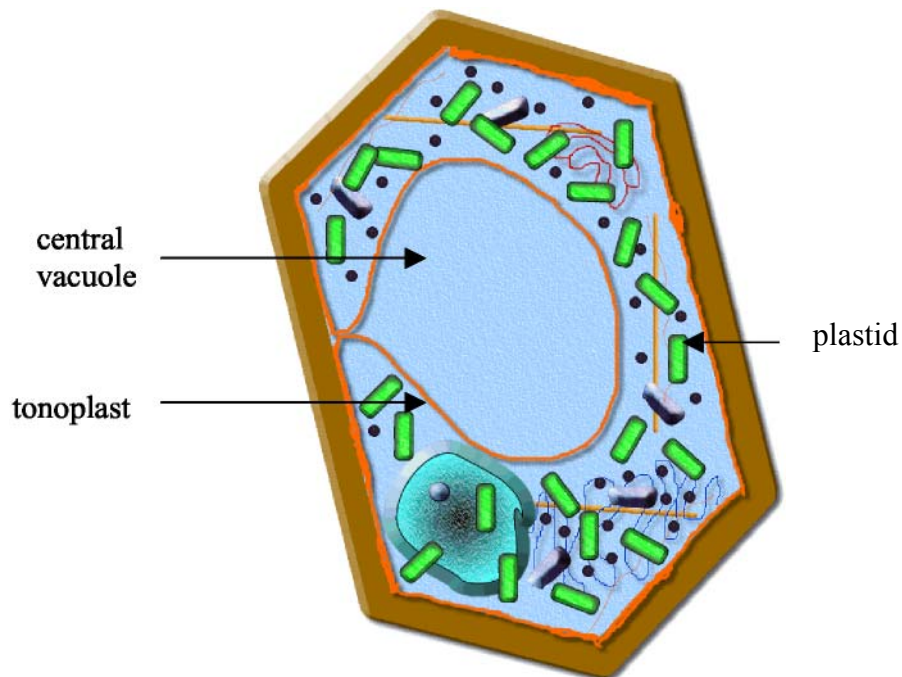


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Plant Cells

Up to this point, the discussion of eukaryotic cells has been about eukaryotic *animal* cells. It's now time to discuss eukaryotic *plant* cells. There are many similarities, however there are some major differences between plant and animal cells. Similar to animal cells, plant cells have a nucleus, endoplasmic reticula, Golgi apparatuses, mitochondria, microfilaments and microtubules, and ribosomes. There are some things that plant cells have that animal cells don't. We'll concentrate on four things.

Structure	Plant	Animal
Cell wall	Plants have a cell wall composed of cellulose	Animal cells don't have cell walls
Central Vacuole	<i>Mature</i> plant cells have a large central vacuole	Animal cells may have vacuoles, but not large central ones
Centrioles	Plant cells <i>typically</i> don't have centrioles	Animal cells have centrioles
Plastids	Plant cells have plastids	Animal cells don't have plastids



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Cell Walls

Plants have rigid cell walls. These walls are composed primarily of cellulose (remember the β , 1-4 linked glucose). There are other components associated with plant cell walls. For example, the cellulose fibers are cemented together to form a very strong structure by the compound called lignin.

Central Vacuole

The central vacuole is that region of the plant cell, mostly toward the center, that takes up the majority of the space of a plant cell. The central vacuole contains cell sap. The sap is mostly water, but there are other materials dissolved within the sap, such as salts, minerals, proteins, and especially pigments.

The central vacuolar membrane is actually a continuation of the cell membrane (much like the endoplasmic reticulum is a continuation of the nuclear membrane). Botanists give the vacuolar membrane a special name – the tonoplast.

Centrioles

Plant cells typically don't produce centrioles. There are some rare cases that they do, but normally, centrioles are absent. Centrioles are utilized in cell division and in the formation of a spindle during mitosis. Plant do produce spindles, just not the centrioles.

Plastids

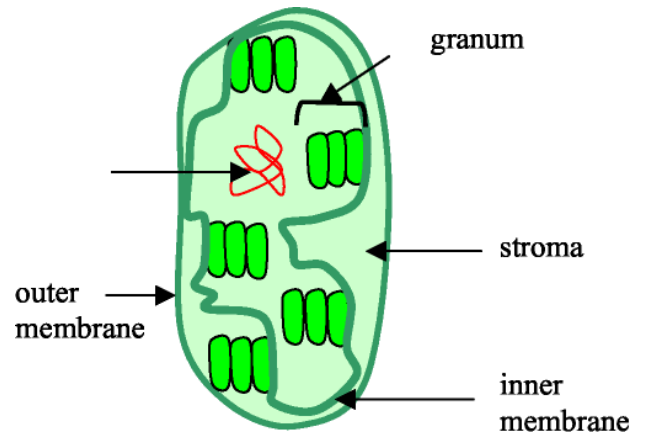
These are what most people refer to as chloroplasts. However, plants produce more than just chloroplasts, so the more appropriate term is that plant cells have plastids. Plastids come in two major forms with subdivisions of each form.

Plastid Types

1. chromoplasts (colored plastids)
 - a. chloroplasts (contain the green pigment chlorophyll)
2. leucoplasts (colorless plastids)
 - a. amyloplasts (starch grains)

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Plastids are remarkably similar to mitochondria. Like mitochondria, they have an inner and outer membrane. The inner membrane, instead of having finger-like projections of the mitochondria, have stacks of membranes. Think of a roll of pennies. The roll of pennies would be analogous to the stacks in the chloroplast called grana. For example, there are numerous grana within a chloroplast. Each individual penny in the roll is what makes up the granum. These are called thylakoids. It is in the thylakoids that chlorophyll, the green pigment in chloroplasts is stored.

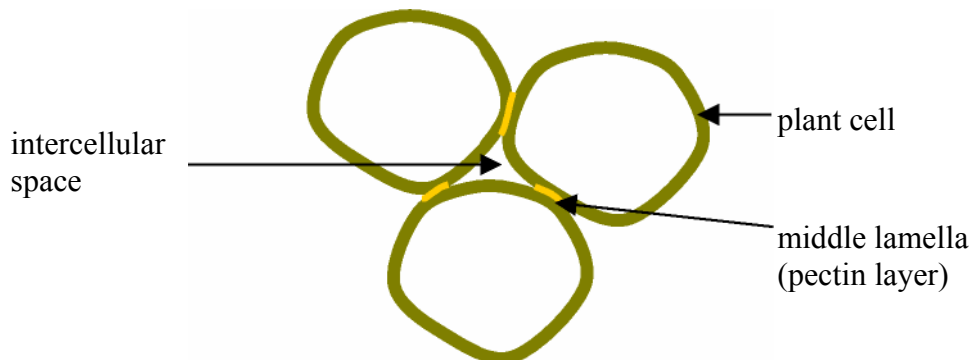


Just as the mitochondrion has a matrix – the protoplasmic-like material inside the mitochondrion, the plastid has the same material. Botanists, however, call it the stroma – not matrix. In addition, plastids contain DNA. It is single copy, circular, and contains non-histone proteins. As a consequence, Lynn Margulis said these are not chloroplasts. Instead, she said they are photosynthetic prokaryotic cells living in a mutualistic relationship with eukaryotic *plant* cells. The question is, “Why do plants have plastids and animals don’t”?

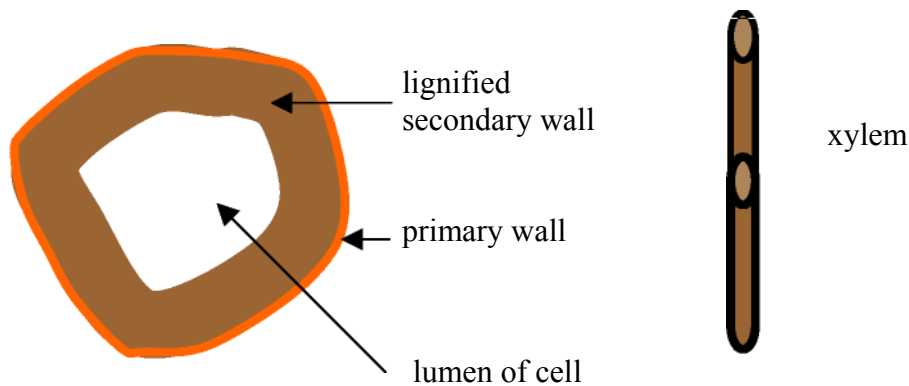
Plant cells, of course, don’t exist singly in nature. Instead, plant cells are connected to others to form the multicellular plant, such as an oak tree. How are the cells joined and how are they connected?

Where one plant cell wall meets another, the cells are “glued” together by a material called pectin. Pectin serves as the “mortar” used to lay bricks. Since plant cells are often multisided, there may be gaps where two cells do not meet. These spaces are called intercellular spaces (between cells). Don’t confuse the term intercellular with intracellular. Intracellular refers to objects *inside* a cell.

The layer of pectin between two cells is called the middle lamella. When fruit ripens, the pectin layer decomposes and there’s nothing to hold the cells together, thus the mushiness of ripened fruit.



Plant cells may also produce a second wall, appropriately called the secondary wall. The cell membrane is responsible for the production of the first wall (primary wall) and the secondary wall. Students often confuse the location of each. Most students think of the secondary wall outside the primary, but the reverse is true. When the secondary wall is produced, the wall becomes embedded with a waterproof material called lignin. Since the cell can no longer obtain water or food due to the lignification of the wall, the cell dies. At first, this seems silly. Why produce a secondary wall if it results in the death of the cell. The answer is found in what happens to the dead cell. If aligned with others, the ends often decompose and form a tube like system of cells for the conduction of water. This is called the xylem in vascular plants.



Plant cells are also in communication with one another. The protoplasm of one plant cell connects to the protoplasm of another plant cell by bridges between them called plasmodesmata (plasmodesma, singular).