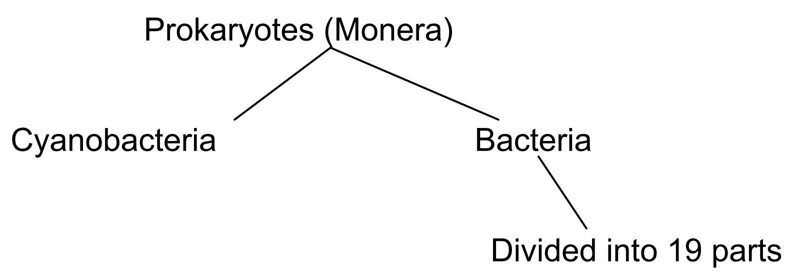
COMPETENCY 1.0 UNDERSTAND CELL STRUCTURE AND FUNCTION

Skill 1.1 Demonstrating knowledge of the components of cells (e.g., cell membrane, cell wall, ribosome, nucleus, mitochondrion, chloroplast) and how the structure of cell organelles relates to their function

The cell is the basic unit of all living things. There are three types of cells: prokaryotic, eukaryotic, and archaea. Archaea have some similarities with prokaryotes, but are as distantly related to prokaryotes as prokaryotes are to eukaryotes.

PROKARYOTES

Prokaryotes consist only of bacteria and cyanobacteria (formerly known as blue-green algae). The diagram below shows the classification of prokaryotes.



Bacterial cells have no defined nucleus or nuclear membrane. The DNA, RNA, and ribosomes float freely within the cell. The cytoplasm has a single chromosome condensed to form a **nucleoid**. Prokaryotes have a thick cell wall made up of amino sugars (glycoproteins) that provides protection, gives the cell shape, and keeps the cell from bursting. The antibiotic penicillin targets the **cell wall** of bacteria. Penicillin works by disrupting the cell wall, thus killing the cell.

The cell wall surrounds the **plasma membrane** (cell membrane). The plasma membrane consists of a lipid bilayer that controls the passage of molecules in and out of the cell. Some prokaryotes have a capsule made of polysaccharides that surrounds the cell wall for extra protection from other organisms or the environment.

Many bacterial cells have appendages used for movement called **flagella**. Some cells also have **pili**, which are a protein strand used for attachment. Pili may also be used for sexual conjugation (where bacterial cells exchange DNA).

Prokaryotes are the most numerous and widespread organisms on earth. Bacteria were most likely the first cells and evidenece of them dates back in the fossil record to 3.5 billion years ago. Their ability to adapt to the environment allows them to thrive in a wide variety of habitats.

EUKARYOTES

Eukaryotic cells are found in protists, fungi, plants, and animals. Most eukaryotic cells are larger than prokaryotic cells. They contain many organelles, which are membrane-bound areas used for specific functions. Their cytoplasm contains a cytoskeleton which provides a protein framework for the cell. The cytoplasm also supports the organelles and contains the ions and molecules necessary for cell function. The cytoplasm is contained by the plasma membrane. The plasma membrane allows molecules to pass in and out of the cell. The membrane can bud inward to engulf outside material in a process called endocytosis. Exocytosis is a secretory mechanism, the reverse of endocytosis.

ARCHAEA

There are three kinds of organisms with archaea cells: **methanogens**, obligate anaerobes that produce methane, **halobacteria**, which can live only in concentrated brine solutions, and **thermoacidophiles**, which can live only in acidic hot springs.

Compare and contrast archaea, prokaryotes, and eukaryotes

The most significant difference between prokaryotes and eukaryotes is that eukaryotes have a **nucleus**. The nucleus is the “brain” of the cell that contains all of the cell’s genetic information. The chromosomes consist of chromatin, which are complexes of DNA and proteins. The chromosomes are tightly coiled to conserve space while providing a large surface area. The nucleus is the site of transcription of the DNA into RNA. The **nucleolus** is where ribosomes are made. There is at least one of these dark-staining bodies inside the nucleus of most eukaryotes. The nuclear envelope consists of two membranes separated by a narrow space. The envelope contains many pores that let RNA out of the nucleus.

Ribosomes are the site for protein synthesis. Ribosomes may be free floating in the cytoplasm or attached to the endoplasmic reticulum. There may be up to a half a million ribosomes in a cell, depending on how much protein the cell makes. Ribosomes are found in both prokaryotic and eukaryotic cells.

The **endoplasmic reticulum** (ER) is folded and has a large surface area. It is the "roadway" of the cell and allows for transport of materials through and out of the cell. There are two types of ER: smooth and rough. Smooth endoplasmic reticula contain no ribosomes on their surface and are the site of lipid synthesis. Rough endoplasmic reticula have ribosomes on their surface and aid in the synthesis of proteins that are membrane bound or destined for secretion. The endoplasmic reticulum is found only in eukaryotic cells.

Many of the products made in the ER proceed to the Golgi apparatus. The **Golgi apparatus** functions to sort, modify, and package molecules that are made in the other parts of the cell (like the ER). These molecules are either sent out of the cell or to other organelles within the cell. The Golgi apparatus is found only in eukaryotic cells.

Lysosomes are found mainly in animal cells. These contain digestive enzymes that break down food, unnecessary substances, viruses, damaged cell components, and, eventually, the cell itself. It is believed that lysosomes play a role in the aging process. Lysosomes are found only in eukaryotic cells.

Mitochondria are large organelles that are the site of cellular respiration, the production of ATP that supplies energy to the cell. Muscle cells have many mitochondria because they use a great deal of energy. Mitochondria have their own DNA, RNA, and ribosomes and are capable of reproducing by binary fission if there is a great demand for additional energy. Mitochondria have two membranes: a smooth outer membrane and a folded inner membrane. The folds inside the mitochondria are called cristae. They provide a large surface area for cellular respiration to occur. The space inside the innermost membrane is called the matrix. Mitochondria are found only in eukaryotic cells.

Plastids are found only in photosynthetic organisms. They are similar to the mitochondira due to the double membrane structure. They also have their own DNA, RNA, and ribosomes and can reproduce if the need for the increased capture of sunlight becomes necessary. There are several types of plastids. **Chloroplasts** are the site of photosynthesis. The stroma is the thick fluid inside the chloroplast's inner membrane space. The stoma encloses sacs called thylakoids that contain the photosynthetic pigment chlorophyll. The chlorophyll traps sunlight inside the thylakoid to generate ATP which is used in the stroma to produce carbohydrates and other products. The **chromoplasts** make and store yellow and orange pigments. They provide color to leaves, flowers, and fruits. The **amyloplasts** store starch and are used as a food reserve. They are abundant in roots like potatoes. Plastids are found only in eukaryotic cells.

The Endosymbiotic Theory states that mitochondria and chloroplasts were once free living and possibly evolved from prokaryotic cells. At some point in eukaryotic evolutionary history, they entered the eukaryotic cell and maintained a symbiotic relationship with the cell, with both the cell and organelle benefiting from the relationship. The fact that they both have their own DNA, RNA, ribosomes, and are capable of reproduction supports this theory.

Found only in plant cells or prokaryotic cells, the **cell wall** is composed of cellulose and fibers. It is thick enough for support and protection, yet porous enough to allow water and dissolved substances to enter. **Vacuoles** are found mostly in plant cells. They hold stored food and pigments. Their large size allows them to fill with water in order to provide turgor pressure. Lack of turgor pressure causes a plant to wilt. Vacuoles are found only in eukaryotic cells.

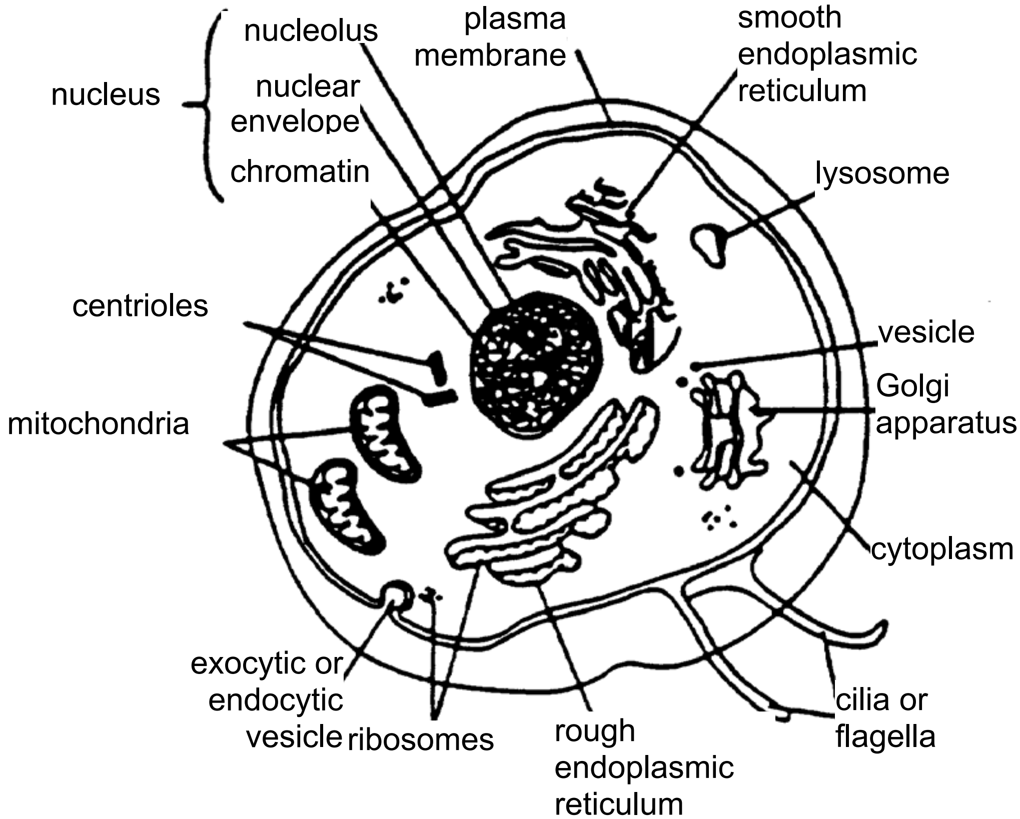
The **cytoskeleton**, found in both animal and plant cells, is composed of protein filaments attached to the plasma membrane and organelles. The cytoskeleton provides a framework for the cell and aids in cell movement. Three types of fibers make up the cytoskeleton:

1. **Microtubules** – The largest of the three fibers, they make up cilia and eukaryotic flagella for locomotion. Some examples are sperm cells, cilia that line the fallopian tubes, and tracheal cilia. Centrioles are also composed of microtubules. They aid in cell division to form the spindle fibers that pull the cell apart into two new cells. Centrioles are not found in the cells of higher plants.

2. **Intermediate filaments** – Intermediate in size, they are smaller than microtubules, but larger than microfilaments. They help the cell keep its shape.

3. **Microfilaments** – Smallest of the three fibers, they are made of actin and small amounts of myosin. They function in cell movement like cytoplasmic streaming, endocytosis, and ameboid movement. Microfilaments are used to pinch the cell into two parts after cell division, forming two new cells by a process known as cytokinesis.

The following is a diagram of a generalized animal cell.



Skill 1.2 Comparing the characteristics of prokaryotic and eukaryotic cells

See Skill 1.1

Skill 1.3 Analyzing the interactions among cell organelles (e.g., phagocytosis)

The transport of large molecules depends on the fluidity of the membrane, which is controlled by cholesterol in the membrane. **Exocytosis** is the release of large particles by vesicles fusing with the plasma membrane. In the process of **endocytosis**, the cell takes in macromolecules and particulate matter by forming vesicles derived from the plasma membrane. There are three types of endocytosis in animal cells. **Phagocytosis** is when a particle is engulfed by pseudopodia and packaged in a vacuole. In **pinocytosis**, the cell takes in extracellular fluid in small vesicles. **Receptor-mediated endocytosis** is when the membrane vesicles bud inward to allow a cell to take in large amounts of certain substances. The vesicles have proteins with receptors that are specific for the substance.

Skill 1.4 Demonstrating knowledge of the structure and function of different types of cell (e.g., muscle cells, nerve cells, guard cells)

The function of different systems in organisms from bacteria to humans dictates system structure. The basic principle that “form follows function” applies to all organismal systems. We will discuss a few examples to illustrate this principle. Keep in mind that we can relate the structure and function of all organismal systems.

Mitochondria, subcellular organelles present in eukaryotic cells, provide energy for cell functions. Much of the energy-generating activity takes place in the mitochondrial inner membrane. To maximize this activity, the mitochondrial membrane has many folds to pack a relatively large amount of membrane into a small space.

Bacterial cells maintain a high surface area to volume ratio to maximize contact with the environment and allow for exchange of nutrients and waste products. Bacterial cells achieve this high ratio by maintaining a small internal volume by cell division.

The cardiovascular system of animals has many specialized structures that help achieve the function of delivering blood to all parts of the body. The heart has four chambers for the delivery and reception of blood. The blood vessels vary in size to accommodate the necessary volume of blood. For example, vessels near the heart are large to accommodate large amounts of blood and vessels in the extremities are very small to limit the amount of blood delivered.

Animals use muscles to convert the chemical energy of ATP into mechanical work. A muscle is composed of bundles of specialized cells capable of creating movement through a combination of contraction and relaxation. Muscle fibers are grouped according to where they are found (skeletal muscle, smooth muscle, and cardiac muscle). A skeletal muscle fiber is not a single cell, but is commonly thought of as the unit of a muscle and is composed of myofibrils. Smooth muscle, including the human heart, is composed of individual cells each containing thick (myosin) and thin (actin) filaments that slide against each other to produce contraction of the cell.

All cells exhibit a voltage difference across the cell membrane. In animals, nerve cells and muscle cells are excitable. Their cell membrane can produce electrochemical impulses and conduct them along the membrane. The nerve cell may be divided into three main parts: the cell body or soma, short processes called the dendrites, and a single long nerve fiber, the axon. The body of a nerve cell is similar to that of other cells in that it includes the nucleus, mitochondria, endoplasmic reticulum, ribosomes, and other organelles. The dendrites receive impulses from other cells and transfer them to the cell body. The effect of these impulses may be excitatory or inhibitory. The long nerve fiber, the axon, transfers the signal from the cell body to other nerve or muscle cells.

In plants, guard cells control the stomata (openings for gas exchange) found in the epidermis of the leaf. These plant cells are regulated by the environmental factors of light intensity, CO_2 concentration and water availability. When the guard cells are activated, potassium pumps actively transport K^+ (potassium) into the guard cells, resulting in a high concentration of K^+ inside the cells. As a result, water enters the cells by osmosis. This causes the guard cells to swell. When the stoma is open CO_2 can diffuse into the leaf and enter the Calvin Cycle. The oxygen produced in photosynthesis diffuses out of the open stoma. Water vapor also escapes from the stoma by the process of transpiration.

Finally, the structure of the skeletal systems of different animals varies based on the animal’s method of movement. For example, the honeycombed structure of bird bones provides a lightweight skeleton of great strength to accommodate flight. The bones of the human skeletal system are dense, strong, and aligned in such a way as to allow walking on two legs in an upright position.