

DOMAIN I –Subject Matter Understanding and Skill in Biology/Life Science

Competency 1.0 Cell Biology and Physiology

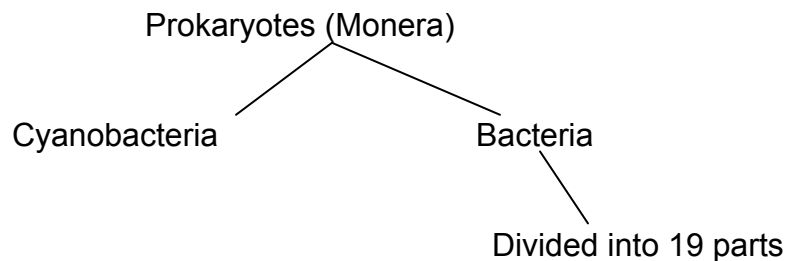
Skill 1.1 Prokaryotic and Eukaryotic Cells

a. Compare prokaryotic cells, eukaryotic cells, and viruses in terms of complexity, general structure, differentiation, and their requirements for growth and replication

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. An application of this is the use of the antibiotic penicillin to target the **cell wall** of bacteria, disrupting the cell wall, and thereby killing the cell.

The cell wall surrounds the **cell membrane** (plasma membrane). The cell 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 higher organisms.

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 date 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.

Most bacteria absorb nutrients from the environment through small channels in their cell walls and membranes (chemotrophs) while some perform photosynthesis (phototrophs). Chemoorganotrophs use organic compounds as energy sources while chemolithotrophs can use inorganic chemicals as energy sources. Depending on the type of metabolism and energy source, bacteria release a variety of waste products (e.g. alcohols, acids, carbon dioxide) to the environment through diffusion.

All bacteria reproduce through binary fission (asexual reproduction) producing two identical cells. Bacteria reproduce very rapidly, dividing or doubling every twenty minutes in optimal conditions. Asexual reproduction does not allow for genetic variation, but bacteria achieve genetic variety by absorbing DNA from ruptured cells and conjugating or swapping chromosomal or plasmid DNA with other cells.

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 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.

The most significant differentiation 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. Inside the nucleus are the chromosomes which consist of chromatin, 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** found inside the nucleus is where ribosomes are made. There is at least one of these dark-staining bodies inside the nucleus of most eukaryotes. The nuclear envelope around the nucleus 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 as many as a half a million ribosomes in a cell, depending on how much protein the cell makes.

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.

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.

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.

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.

Plastids are found only in photosynthetic organisms such as plants. They are similar to the mitochondria 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 chloroplast's inner membrane space. The stroma 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.

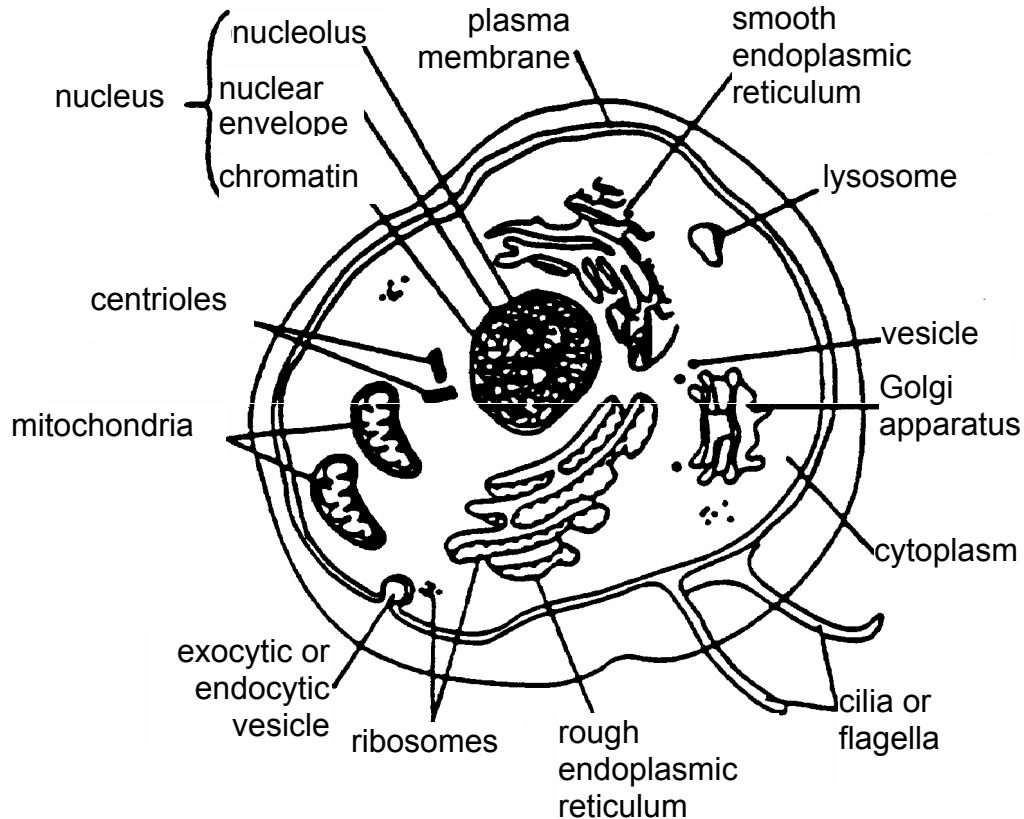
The Endosymbiotic Theory states that mitochondria and chloroplasts were once free living and possibly evolved from prokaryotic cells. At some point in evolutionary history, they entered the eukaryotic cell and maintained a symbiotic relationship with the cell, with both the cell and organelle benefiting 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, 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.

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 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 (like in muscle tissue). They function in cell movement like cytoplasmic streaming, endocytosis, and amoeboid movement. This structure pinches the two cells apart after cell division, forming two new cells.

The following is a diagram of a generalized animal cell.



Animals are multicellular, eukaryotic organisms. All animals obtain nutrients by eating food (ingestion). Different types of animals derive nutrients from eating plants, other animals, or both. Animal cells perform respiration that converts food molecules, mainly carbohydrates and fats, into energy. The excretory systems of animals, like animals themselves, vary in complexity. Simple invertebrates eliminate waste through a single tube, while complex vertebrates have a specialized system of organs that process and excrete waste.

Most animals, unlike bacteria, exist in two distinct sexes. Members of the female sex give birth or lay eggs. Some less developed animals can reproduce asexually. For example, flatworms can divide in two and some unfertilized insect eggs can develop into viable organisms. Most animals reproduce sexually through various mechanisms. For example, aquatic animals reproduce by external fertilization of eggs, while mammals reproduce by internal fertilization. More developed animals possess specialized reproductive systems and cycles that facilitates reproduction and promotes genetic variation.

Plants, like animals, are multi-cellular, eukaryotic organisms. Plants obtain nutrients from the soil through their root systems and convert sunlight into energy through photosynthesis. Many plants store waste products in vacuoles or organs (e.g. leaves, bark) that are discarded. Some plants also excrete waste through their roots.

More than half of the plant species reproduce by producing seeds from which new plants grow. Depending on the type of plant, flowers or cones produce seeds. Other plants reproduce by spores, tubers, bulbs, buds, and grafts. The flowers of flowering plants contain the reproductive organs. Pollination is the joining of male and female gametes that is often facilitated by movement by wind or animals.

Fungi are eukaryotic, mostly multi-cellular organisms. All fungi are heterotrophs, obtaining nutrients from other organisms. More specifically, most fungi obtain nutrients by digesting and absorbing nutrients from dead organisms. Fungi secrete enzymes outside of their body to digest organic material and then absorb the nutrients through their cell walls.

Most fungi can reproduce asexually and sexually. Different types of fungi reproduce asexually by mitosis, budding, sporification, or fragmentation. Sexual reproduction of fungi is different from sexual reproduction of animals. The two mating types of fungi are plus and minus, not male and female. The fusion of hyphae, the specialized reproductive structure in fungi, between plus and minus types produces and scatters diverse spores.

Protists are eukaryotic, single-celled organisms. Most protists are heterotrophic, obtaining nutrients by ingesting small molecules and cells and digesting them in vacuoles. All protists reproduce asexually by either binary or multiple fission. Like bacteria, protists achieve genetic variation by exchange of DNA through conjugation.

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.

VIRUSES

Microbiology includes the study of monera, protists, and viruses. Although **viruses** are not classified as living things, they greatly affect other living things by disrupting cell activity. Viruses are obligate parasites because they rely on the host for their own reproduction. Viruses are composed of a protein coat and a nucleic acid, either DNA or RNA. A bacteriophage is a virus that infects a bacterium. Animal viruses are classified by the type of nucleic acid, presence of RNA replicase, and presence of a protein coat.

There are two types of viral reproductive cycles:

1. **Lytic cycle** - The virus enters the host cell and makes copies of its nucleic acids and protein coats and reassembles them into copies of itself. It then lyses or breaks out of the host cell and infects other nearby cells, repeating the process.
2. **Lysogenic cycle** - The virus may remain dormant within the cell (often for months or years) until some factor activates it and stimulates it to break out of the cell. Herpes is an example of a lysogenic virus.

Skill 1.2 Cellular Reproduction

a. Describe the stages of the cell cycle

The purposes of cell division are to provide growth and repair in body (somatic) cells and to replenish or create sex cells for reproduction. There are two forms of cell division: mitosis and meiosis. **Mitosis** is the division of somatic cells and **meiosis** is the division of sex cells (eggs and sperm).

b. Diagram and describe the stages of the mitotic process

Mitosis is divided into two parts: the **mitotic (M) phase** and **interphase**. In the mitotic phase, mitosis and cytokinesis divide the nucleus and cytoplasm, respectively. This phase is the shortest phase of the cell cycle. Interphase is the stage where the cell grows and copies the chromosomes in preparation for the mitotic phase. Interphase occurs in three stages of growth: the **G1** (growth) period, when the cell grows and metabolizes, the **S** (synthesis) period, when the cell makes new DNA, and the **G2** (growth) period, when the cell makes new proteins and organelles in preparation for cell division.

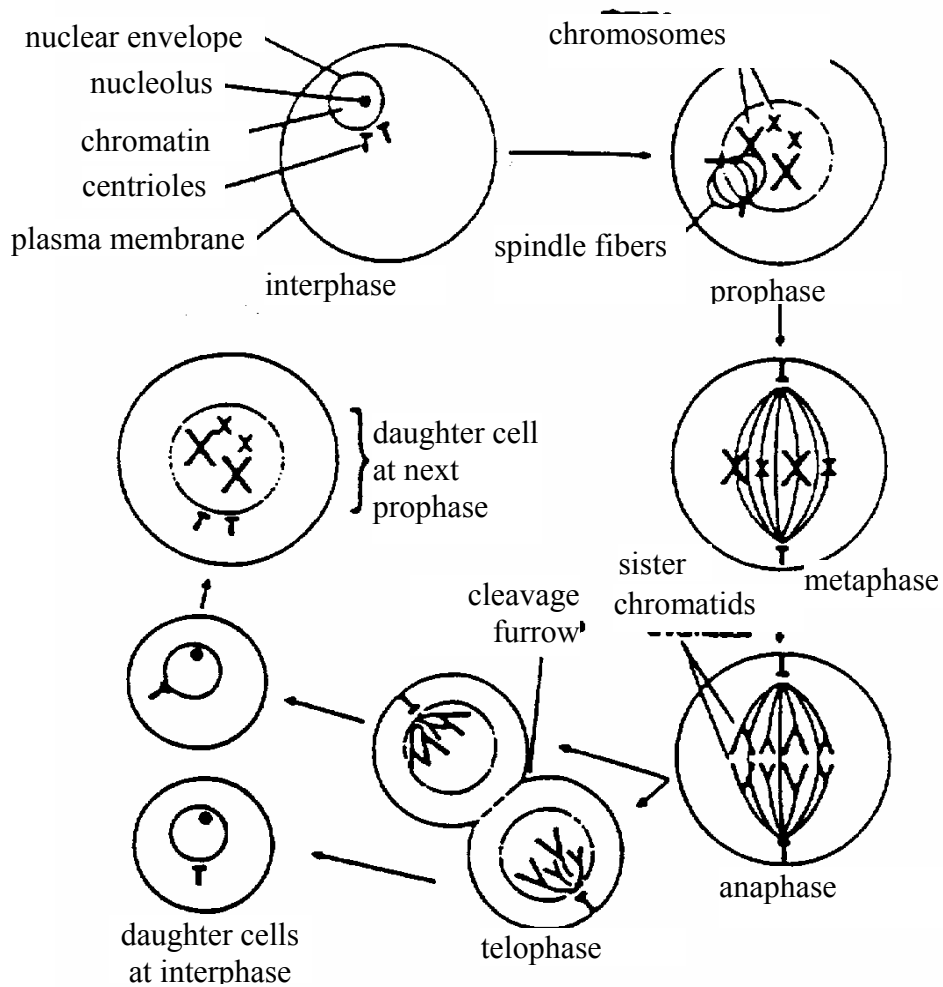
The mitotic phase is a continuum of change, although we divide it into five distinct stages: prophase, prometaphase, metaphase, anaphase, and telophase.

During **prophase**, the cell proceeds through the following steps continuously, without stopping. First, the chromatin condenses to become visible chromosomes. Next, the nucleolus disappears and the nuclear membrane breaks apart. Then, mitotic spindles composed of microtubules form that will eventually pull the chromosomes apart. Finally, the cytoskeleton breaks down and the action of centrioles pushes the spindles to the poles or opposite ends of the cell.

During **prometaphase**, the nuclear membrane fragments and allows the spindle microtubules to interact with the chromosomes. Kinetochore fibers attach to the chromosomes at the centromere region. **Metaphase** begins when the centrosomes are at opposite ends of the cell. The centromeres of all the chromosomes are aligned with one another.

During **anaphase**, the centromeres split in half and homologous chromosomes separate. The chromosomes are pulled to the poles of the cell, with identical sets at either end. The last stage of mitosis is **telophase**. Here, two nuclei form with a full set of DNA that is identical to the parent cell. The nucleoli become visible and the nuclear membrane reassembles. A cell plate is seen in plant cells and a cleavage furrow forms in animal cells. The cell pinches into two cells. Finally, cytokinesis, or division of the cytoplasm and organelles, occurs.

Below is a diagram of mitosis.



Mitosis in an Animal Cell

Meiosis is similar to mitosis, but there are two consecutive cell divisions, meiosis I and meiosis II in order to reduce the chromosome number by one half. This way, when the haploid sperm and haploid egg join during fertilization, so the diploid number is reached.

Similar to mitosis, meiosis is preceded by an interphase during which the chromosome replicates. The steps of meiosis are as follows:

1. **Prophase I** – The replicated chromosomes condense and pair with homologues in a process called synapsis. This forms a tetrad. Crossing over, the exchange of genetic material between homologues to further increase diversity, occurs during prophase I if it is going to occur.
2. **Metaphase I** – The homologous pairs attach to spindle fibers after lining up in the middle of the cell.
3. **Anaphase I** – The sister chromatids remain joined and move to the poles of the cell.
4. **Telophase I** – The homologous chromosome pairs continue to separate. Each pole now has a haploid chromosome set. Telophase I occurs simultaneously with cytokinesis. In animal cells, a cleavage furrow forms and, in plant cells, a cell plate appears.
5. **Prophase II** – A spindle apparatus forms and the chromosomes condense.
6. **Metaphase II** – Sister chromatids line up in center of cell. The centromeres divide and the sister chromatids begin to separate.
7. **Anaphase II** – The separated chromosomes move to opposite ends of the cell.
8. **Telophase II** – Cytokinesis occurs, resulting in four haploid daughter cells.

Below is a diagram of meiosis.

