Introduction to cell

Introduction

A. Definition of a cell: fundamental structural and functional unit of all living organisms

B. Characteristics of cells:

1) Contain highly organized molecular and biochemical systems and are used to store information
2) Use energy
3) Capable of movement
4) Sense environmental changes
5) Can duplicate (transfer genetic information to offspring)
6) Capable of self-regulation

-Most cells are microscopic (invisible to the naked eye) and thus, a microscope is needed to view most cells.

C) History:

-Discovery of the cell followed by the development of the microscope

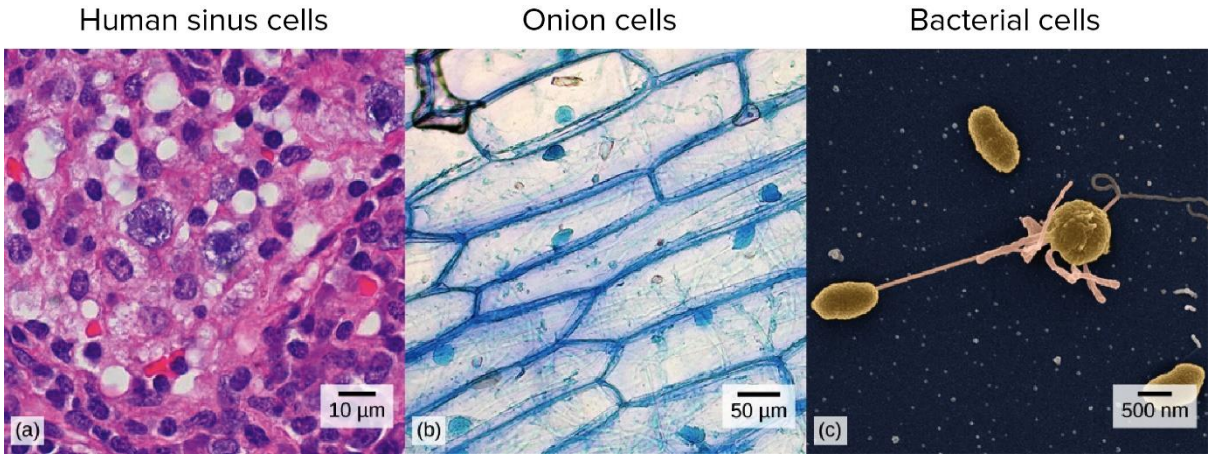
A. 1665-Robert Hooke- observed cells from the fruiting bodies of fungi

B. Anton van Leewenhoek- observed a variety of cells and called them "animalcules"

C. 1830's-Theodor Schwann and Matthias Schleiden developed the cell theory

Cells

- We cannot see the cells with our naked eyes limited by the fact that we cannot resolve two points separated by less than 0.1 mm
- Hence, we need a light microscope to see them
- Cells are smaller and could be at the range of 1 micrometer for bacteria and 30 micrometers for epithelial cells



Micrographs of human, onion, and bacterial cells.

Cell theory

- The term "Cell" was first coined by Robert Hooke in 1655.
- He used magnifying glass to observe the structure of cork and used the term "cell" to refer to the hollow space (Cella in Latin) found in corks
- Brown (1831) stated that all cells have a nucleus and the cell content was called protoplasm. Later karyoplasm was used to refer to the protoplasm within the nucleus

- Cell theory states that all living organisms should have cells and cell products. Schleiden and Schwann (1839)
- Virchow (1855) stated “Omnis cellulae e cellula” meaning that all cells arise from preexisting cells

Modern Cell Biology

- Gregor Mendel discovered the fundamental laws of heredity (1865)
- Miescher (1871) isolated nuclein, what is now called DNA, from white blood cells
- Thomas Hunt Morgan provided convincing evidence that chromosomes are the location of Mendel’s heritable factors
- Structure of DNA by Watson and Crick (1953). A copying mechanism proposed by them was revolutionary and could explain as to how the genetic material could be transferred from the parent to the offspring.
- “Nothing in biology makes sense except in the light of evolution” (Theodosius Dobzhansky 1900-1975)
- The Theory of Evolution by Natural Selection and the Central Dogma of Molecular Biology are the twin pillars supporting Modern Biology

The ideas of all these early thinkers are summarized in **modern cell theory**, which states:

1. **All living things are composed of one or more cells.**
2. **The cell is the basic unit of life.**
3. **New cells arise from pre-existing cells.**

Classification of cells

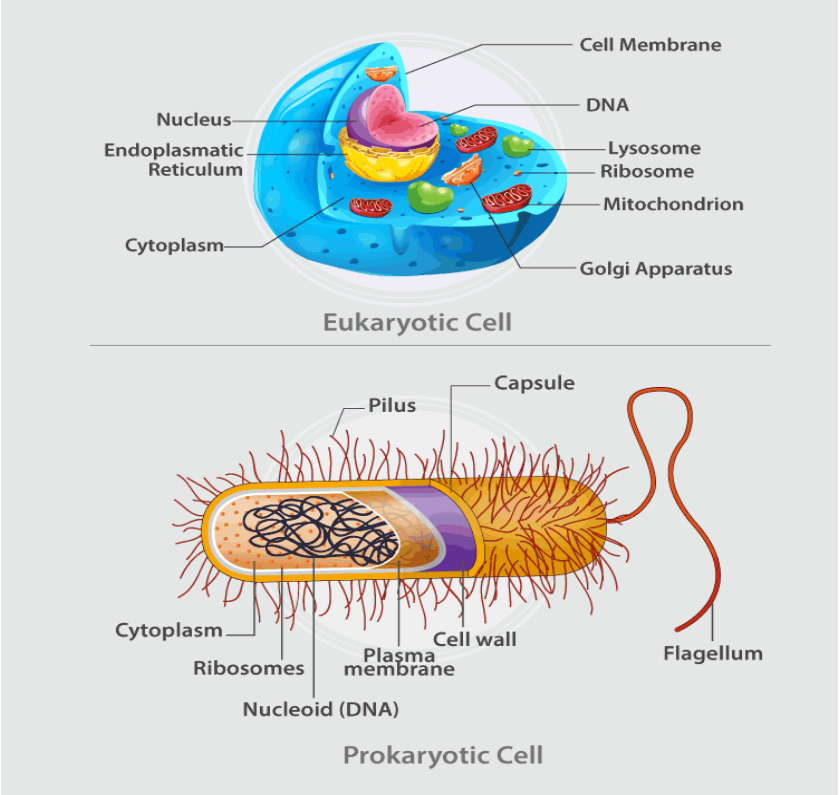
All living organisms (bacteria, blue green algae, plants and animals) have cellular organization and may contain one or many cells. The organisms with only one cell in their body are called unicellular organisms (bacteria, blue green algae, some algae, Protozoa, etc.). The organisms having many cells in their body are called multicellular organisms (fungi, most plants and animals). Any living organism may contain only one type of cell either **A. Prokaryotic cells; B. Eukaryotic cells.** The terms prokaryotic and eukaryotic were suggested by Hans Ris in the 1960’s. This classification is based on their complexcity. Further based on the kingdom into which they may fall i.e the plant or the animal kingdom, plant and animal cells bear many differences.

Prokaryotes and Eukaryotes

Biotic components of the environment include all forms of life from minute bacteria to towering giant sequoias. But at the microscopic level, all living organisms are made up of the same basic unit – the cell.

As a result, the cell is referred to as the structural and functional unit of all living organisms. The word cell has its origins from Latin, and when translated, it means “small room” and was first observed by Robert Hooke – an English natural philosopher in the year 1665.

He also compared his discovery to the cells in a honeycomb, as they showcase a similar structure.



An image illustrating the difference between Prokaryotic and Eukaryotic Cells. Note that the prokaryotic cell is a complete individual organism

Eventual advancements in science and technology shed more light into the cell, with new findings and discoveries about its structure and cellular components. During the 1950s, scientists postulated the concept of prokaryotic cell and eukaryotic cell, with earlier groundwork being laid by Edouard Chatton, a French Biologist in 1925.

Anatomically, cells vary with respect to their classification, therefore, prokaryotic cells and eukaryotic cells differ from each other quite drastically. Read on to explore how they differ from each other.

Prokaryotic Cell

The term “**prokaryote**” is derived from the Greek word “*pro*“, (meaning: before) and “*karyon*” (meaning: kernel). It translates to “***before nuclei.*** “

Prokaryotes are one of the most ancient groups of living organisms on earth, with fossil records dating back to almost 3.5 billion years ago.

These prokaryotes thrived in the earth's ancient environment, some using up chemical energy and others using the sun's energy. These extremophiles thrived for millions of years, evolving and adapting. Scientists speculate that these organisms gave rise to the eukaryotes.

Prokaryotic cells are comparatively smaller and much simpler than eukaryotic cells. The other defining characteristic of prokaryotic cells is that it does not possess membrane-bound cell organelles such as a nucleus. Reproduction happens through the process of binary fission.

Structurally, prokaryotes have a capsule enveloping its entire body, and it functions as a protective coat. This is crucial for preventing the process of phagocytosis (where the bacteria get engulfed by other eukaryotic cells such as macrophages.) The pilus is a hair-like appendage found on the external surface of most prokaryotes and it helps the organism to attach itself to various environments. The pilus essentially resists being flushed, hence, it is also called attachment pili. It is commonly observed in bacteria.

Right below the protective coating lies the cell wall, which provides strength and rigidity to the cell. Further down lies the cytoplasm that helps in cellular growth, and this is contained within the plasma membrane, which separates the interior contents of the cell from the outside environment. Within the cytoplasm, ribosomes exist and it plays an important role in protein synthesis. It is also one of the smallest components within the cell.

Some prokaryotic cells contain special structures called mesosomes which assist in cellular respiration. Most prokaryotes also contain plasmids, which contains small, circular pieces of DNA. And to help with locomotion, flagella are present, though, pilus can also serve as an aid for locomotion. Common examples of Prokaryotic organisms are bacteria and archaea. Also, all members of Kingdom Monera are prokaryotes.

Eukaryotic Cell

The term "**Eukaryotes**" is derived from the Greek word "*eu*", (meaning: good) and "*karyon*" (meaning: kernel), therefore, translating to "***good or true nuclei***." Eukaryotes are more complex and much larger than the prokaryotes. They include almost all the major kingdoms except kingdom monera.

Structurally, eukaryotes possess a cell wall, which supports and protects the plasma membrane. The cell is surrounded by the plasma membrane and it controls the entry and exit of certain substances.

The nucleus contains DNA, which is responsible for storing all genetic information. The nucleus is surrounded by the nuclear membrane. Within the nucleus exists the nucleolus, and it plays a crucial role in synthesising proteins. Eukaryotic cells also contain mitochondria, which are responsible for the creation of energy, which is then utilized by the cell.

Present in only plant cells, chloroplasts are the subcellular sites of photosynthesis. Endoplasmic reticulum helps in the transportation of materials. Besides these, there are also other cell organelles that perform various other functions and these include ribosomes, lysosomes, Golgi bodies, cytoplasm, chromosomes, vacuoles, and centrosomes.

Examples of eukaryotes include almost every unicellular organism with a nucleus and all multicellular organisms.

Difference between Prokaryotic and Eukaryotic Cells

Though these two classes of cells are quite different, they do possess some common characteristics. For instance, both possess cell membrane and ribosomes, but the similarities end there. The complete list of difference between prokaryotic and eukaryotic cells are summarized as follows:

	Prokaryotes	**Eukaryotes**
Type of Cell	Always unicellular	Unicellular and multi-cellular
Cell size	Ranges in size from 0.2 μm – 2.0 μm in diameter	Size ranges from 10 μm – 100 μm in diameter
Cell wall	Usually present; chemically complex in nature	When present, chemically simple in nature
Nucleus	Absent	Present
Ribosomes	Present. Smaller in size and spherical in shape	Present. Comparatively larger in size and linear in shape
DNA arrangement	Circular	Linear
Mitochondria	Absent	Present
Cytoplasm	Present, but cell organelles absent	Present, cell organelles present
Endoplasmic reticulum	Absent	Present
Plasmids	Present	Very rarely found in eukaryotes
Ribosome	Small ribosomes	Large ribosomes
Lysosome	In this, the lysosome, mesosome, and centrosome is absent	Mesosome, Lysosomes, and centrosomes are present
Cell division	Through binary fission	Through mitosis

Flagella	The flagella are smaller in size	The flagella are larger in size
Reproduction	Asexual	Both asexual and sexual
Example	Bacteria and Archaea	Plant and Animal cell

Difference between plant and animal cells

Both plant and animal cells are eukaryotic, so they contain membrane-bound organelles like the nucleus and mitochondria.

However, plant cells and animal cells do not look exactly the same or have all of the same organelles, since they each have different needs. For example, plant cells contain chloroplasts since they need to perform photosynthesis, but animal cells do not.

Diagram of a typical animal cell:

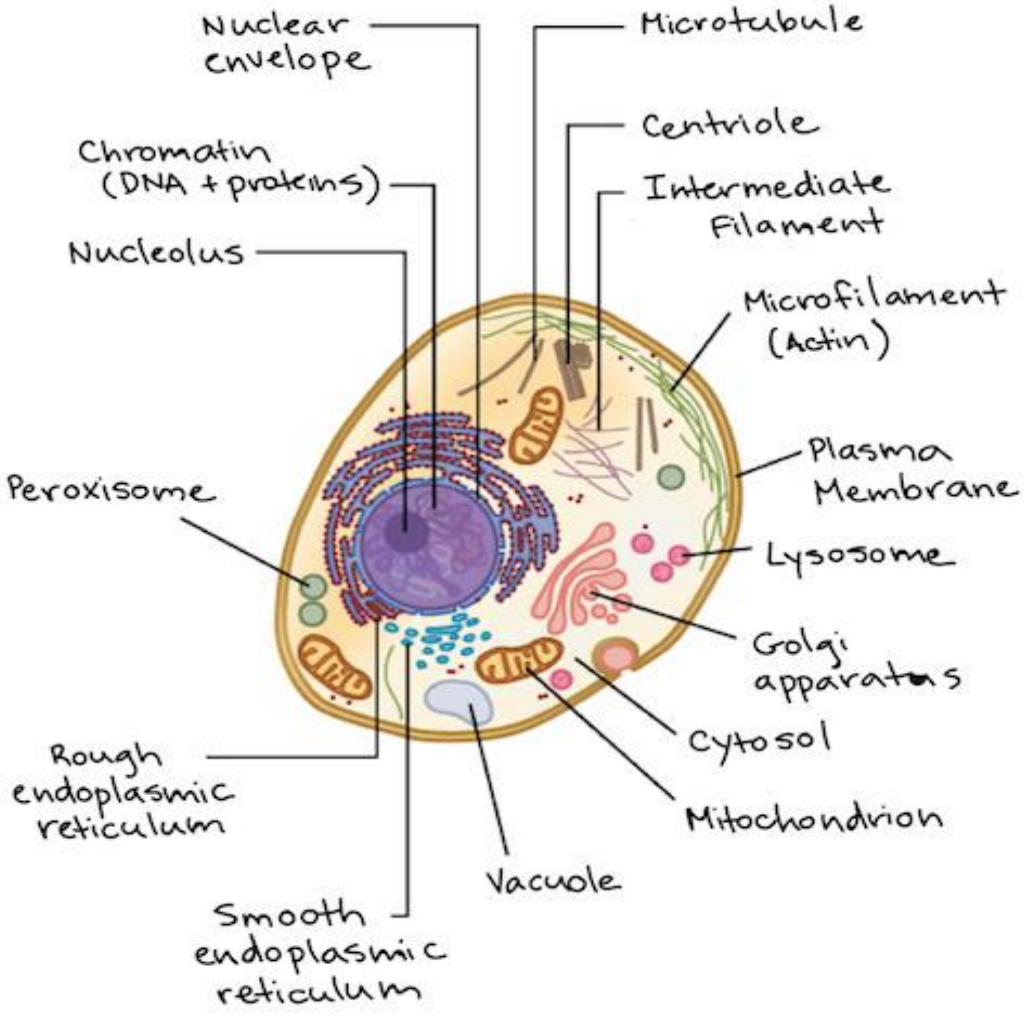


Diagram of an animal cell with components lettered.

Diagram of a typical plant cell:

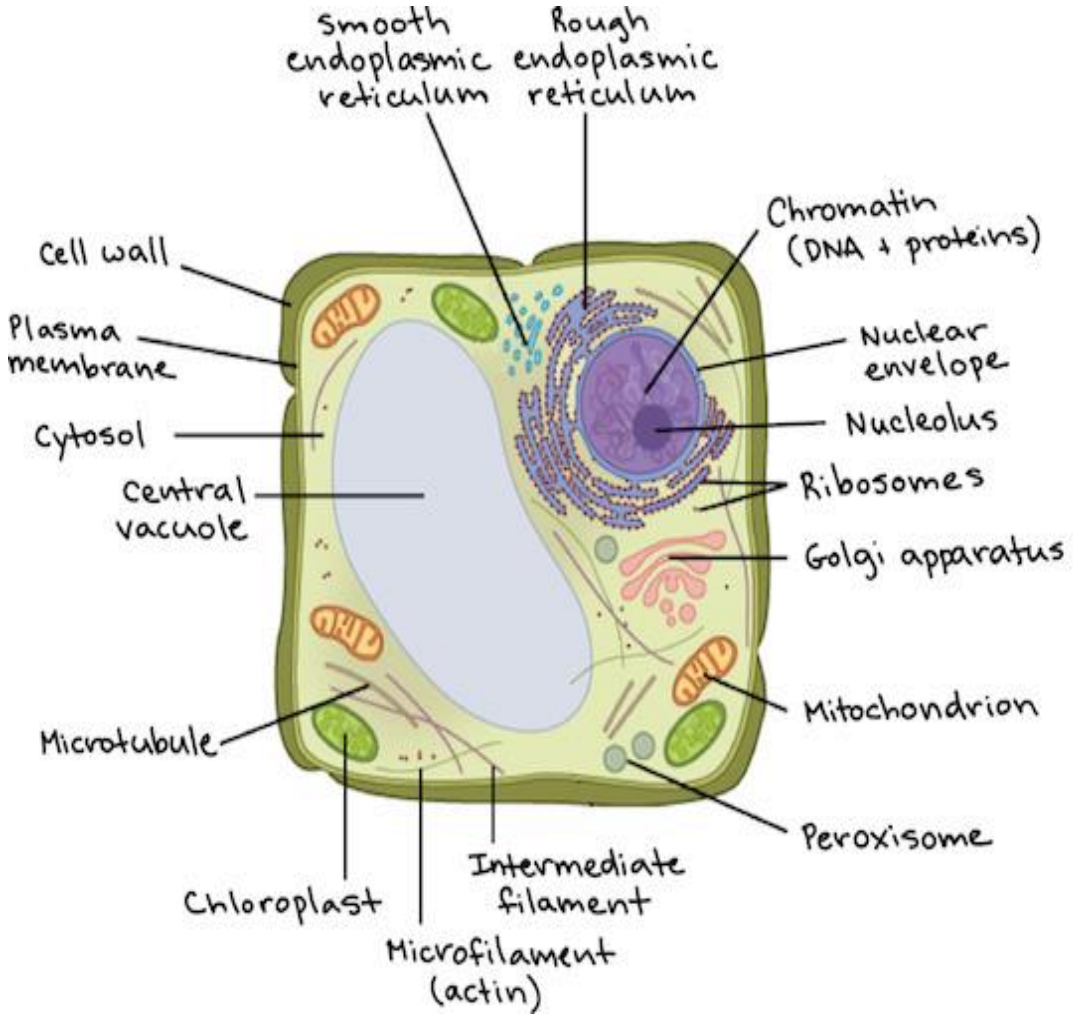


Diagram of a plant cell with components labelled.

- **Both animal and plant cells have mitochondria, but only plant cells have chloroplasts.** Plants don't get their sugar from eating food, so they need to make sugar from sunlight. This process (photosynthesis) takes place in the chloroplast. Once the sugar is made, it is then broken down by the mitochondria to make energy for the cell. Because animals get sugar from the food they eat, they do not need chloroplasts: just mitochondria.
- **Both plant and animal cells have vacuoles.** A plant cell contains a large, singular vacuole that is used for storage and maintaining the shape of the cell. In contrast, animal cells have many, smaller vacuoles.
- **Plant cells have a cell wall, as well as a cell membrane. In plants, the cell wall surrounds the cell membrane.** This gives the plant cell its unique rectangular shape. Animal cells simply have a cell membrane, but no cell wall.

Cell Wall

The cell wall

Though plants don't make collagen, they have their own type of supportive extracellular structure: the cell wall. The **cell wall** is a rigid covering that surrounds the cell, protecting it and giving it support and shape. Have you ever noticed that when you bite into a raw vegetable, like celery, it crunches? A big part of that crunch is the rigidity of celery's cell walls.

Fungi also have cell walls, as do some protists (a group of mostly unicellular eukaryotes) and most prokaryotes—though I don't recommend biting into any of those to see if they crunch!

Like the animal extracellular matrix, the plant cell wall is made up of molecules secreted by the cell. The major organic molecule of the plant cell wall is **cellulose**, a polysaccharide composed of glucose units. Cellulose assembles into fibers called microfibrils, as shown in the diagram below.

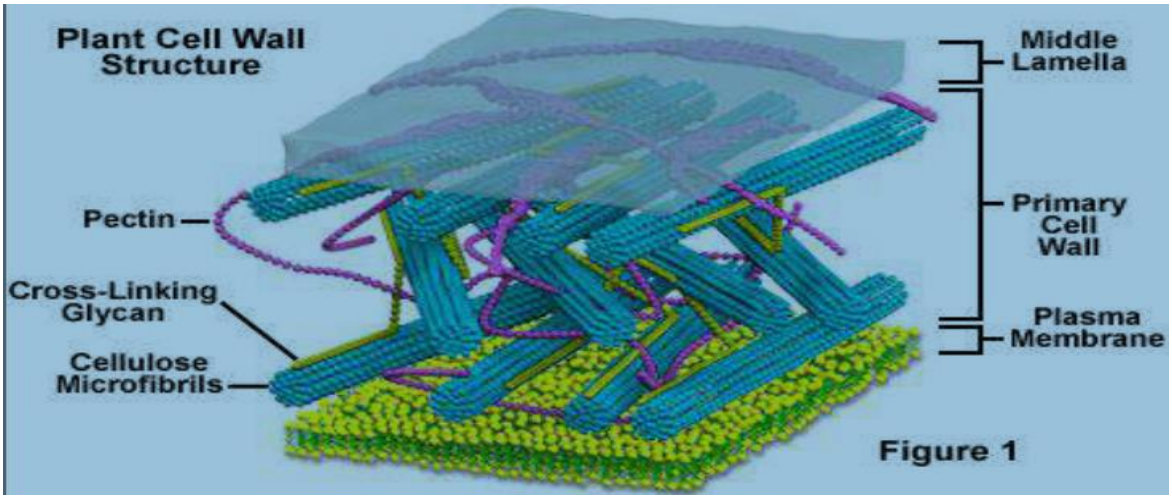


Image of the plant cell wall, showing the network of cellulose microfibrils and pectins (with pectin's being particularly abundant in the middle lamella).

Most plant cell walls contain a variety of different polysaccharides and proteins. In addition to cellulose, other polysaccharides commonly found in the plant cell wall include hemicellulose and pectin, shown in the diagram above. The **middle lamella**, shown along the top of the diagram, is a sticky layer that helps hold the cell walls of adjacent plant cells together.

Plasmodesmata

Plasmodesmata are small channels through cell wall that directly connect the cytoplasm of neighbouring plant cells to each other, establishing continuity between cells, called as sympast. Similar to the gap junctions found in animal cells, the plasmodesmata, which penetrate both the primary and secondary cell walls, allow small molecules to pass directly from one cell to

other and play important role in cellular communication. They are central to the growth, development and defence of all higher plants. Plasmodesmata occur universally in all plant groups, from higher to lower plant groups. They exhibit a quantitative relationship with solute flux and vary in number as well as size.

Role of Plasmodesmata

• **Sympastic transport :** occurs from cell to cell

• **Short distance transport** (translocation eg. Sugar loading from phloem cells to companion Cells)

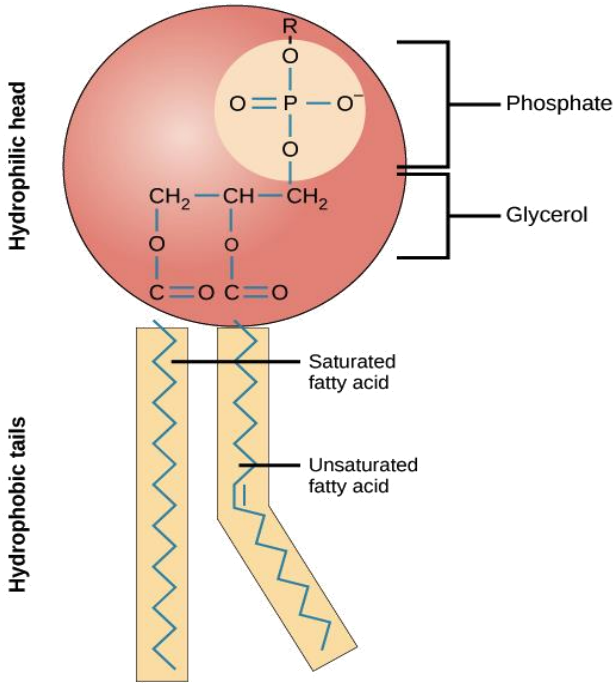
Plasma membrane and cytoplasm

The plasma membrane

Both prokaryotic and eukaryotic cells have a **plasma membrane**, a double layer of lipids that separates the cell interior from the outside environment. This double layer consists largely of specialized lipids called phospholipids.

Phospholipids

Phospholipids, arranged in a bilayer, make up the basic fabric of the plasma membrane. They are well-suited for this role because they are **amphipathic**, meaning that they have both hydrophilic and hydrophobic regions.



Chemical structure of a phospholipid, showing the hydrophilic head and hydrophobic tails.

The **hydrophilic**, or "water-loving," portion of a phospholipid is its head, which contains a negatively charged phosphate group as well as an additional small group (of varying identity, "R" in the diagram at left), which may also or be charged or polar. The hydrophilic heads of phospholipids in a membrane bilayer face outward, contacting the aqueous (watery) fluid both inside and outside the cell. Since water is a polar molecule, it readily forms electrostatic (charge-based) interactions with the phospholipid heads.

The **hydrophobic**, or "water-fearing," part of a phospholipid consists of its long, nonpolar fatty acid tails. The fatty acid tails can easily interact with other nonpolar molecules, but they interact poorly with water. Because of this, it's more energetically favorable for the phospholipids to tuck their fatty acid tails away in the interior of the membrane, where they are shielded from the surrounding water. The phospholipid bilayer formed by these interactions makes a good barrier between the interior and exterior of the cell, because water and other polar or charged substances cannot easily cross the hydrophobic core of the membrane.

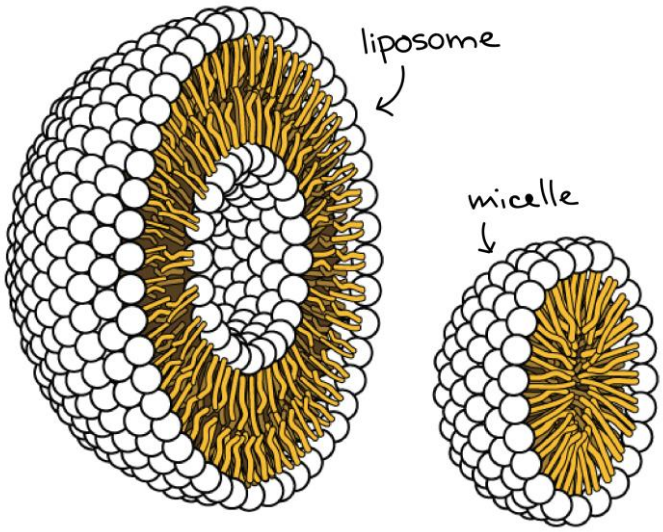


Image of a micelle and a liposome.

Thanks to their amphipathic nature, phospholipids aren't just well-suited to form a membrane bilayer. Instead, this is something they'll do spontaneously under the right conditions! In water or aqueous solution, phospholipids tend to arrange themselves with their hydrophobic tails facing each other and their hydrophilic heads facing out. If the phospholipids have small tails, they may form a **micelle** (a small, single-layered sphere), while if they have bulkier tails, they may form a **liposome** (a hollow droplet of bilayer membrane).

Proteins

Proteins are the second major component of plasma membranes. There are two main categories of membrane proteins: integral and peripheral.

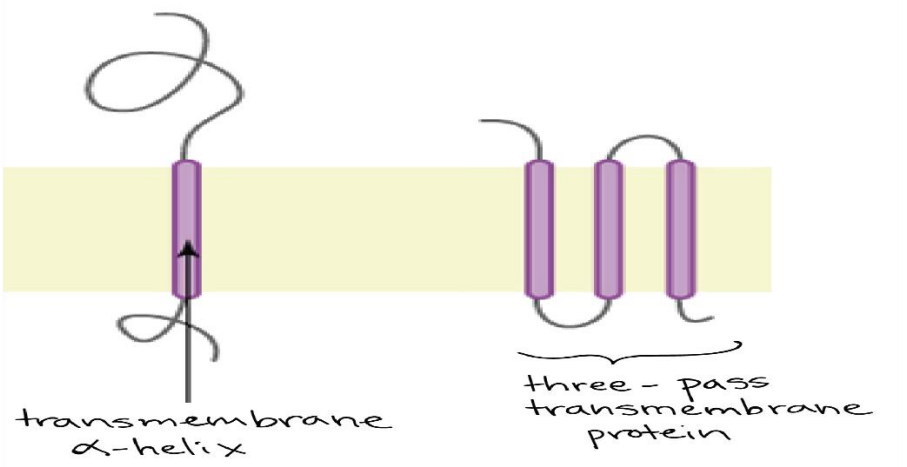
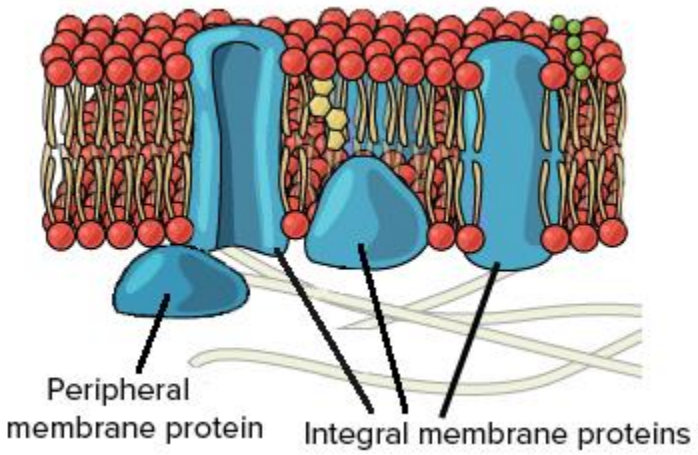


Image of a single-pass transmembrane protein with a single membrane-spanning alpha helix and a three-pass transmembrane protein with three membrane-spanning alpha helices.

Integral membrane proteins are, as their name suggests, integrated into the membrane: they have at least one hydrophobic region that anchors them to the hydrophobic core of the phospholipid bilayer. Some stick only partway into the membrane, while others stretch from one side of the membrane to the other and are exposed on either side^11start superscript, 1, end superscript. Proteins that extend all the way across the membrane are called **transmembrane proteins**.

The portions of an integral membrane protein found inside the membrane are hydrophobic, while those that are exposed to the cytoplasm or extracellular fluid tend to be hydrophilic. Transmembrane proteins may cross the membrane just once, or may have as many as twelve different membrane-spanning sections. A typical membrane-spanning segment consists of 20-25 hydrophobic amino acids arranged in an alpha helix, although not all transmembrane proteins fit this model. Some integral membrane proteins form a channel that allows ions or other small molecules to pass, as shown below.



Peripheral membrane proteins are found on the outside and inside surfaces of membranes, attached either to integral proteins or to phospholipids. Unlike integral membrane proteins, peripheral membrane proteins do not stick into the hydrophobic core of the membrane, and they tend to be more loosely attached.

Carbohydrates

Carbohydrates are the third major component of plasma membranes. In general, they are found on the outside surface of cells and are bound either to proteins (forming **glycoproteins**) or to lipids (forming **glycolipids**). These carbohydrate chains may consist of 2-60 monosaccharide units and can be either straight or branched.

Along with membrane proteins, these carbohydrates form distinctive cellular markers, sort of like molecular ID badges, that allow cells to recognize each other. These markers are very important in the immune system, allowing immune cells to differentiate between body cells, which they shouldn't attack, and foreign cells or tissues, which they should.

Membrane fluidity

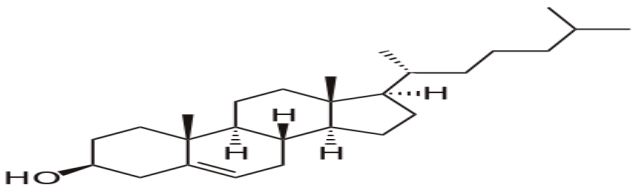
The structure of the fatty acid tails of the phospholipids is important in determining the properties of the membrane, and in particular, how fluid it is.

Saturated fatty acids have no double bonds (are saturated with hydrogens), so they are relatively straight. **Unsaturated** fatty acids, on the other hand, contain one or more double bonds, often resulting in a bend or kink. (You can see an example of a bent, unsaturated tail in the diagram of phospholipid structure that appears earlier in this article.) The saturated and unsaturated fatty acid tails of phospholipids behave differently as temperature drops:

- At cooler temperatures, the straight tails of saturated fatty acids can pack tightly together, making a dense and fairly rigid membrane.
- Phospholipids with unsaturated fatty acid tails cannot pack together as tightly because of the bent structure of the tails. Because of this, a membrane containing unsaturated phospholipids will stay fluid at lower temperatures than a membrane made of saturated ones.

Most cell membranes contain a mixture of phospholipids, some with two saturated (straight) tails and others with one saturated and one unsaturated (bent) tail. Many organisms—fish are one example—can adjust physiologically to cold environments by changing the proportion of unsaturated fatty acids in their membranes. For more information about saturated and unsaturated fatty acids, see the article on lipids.

In addition to phospholipids, animals have an additional membrane component that helps to maintain fluidity. **Cholesterol**, another type of lipid that is embedded among the phospholipids of the membrane, helps to minimize the effects of temperature on fluidity.



"Cholesterol"

At low temperatures, cholesterol increases fluidity by keeping phospholipids from packing tightly together, while at high temperatures, it actually reduces fluidity. In this way, cholesterol expands the range of temperatures at which a membrane maintains a functional, healthy fluidity.

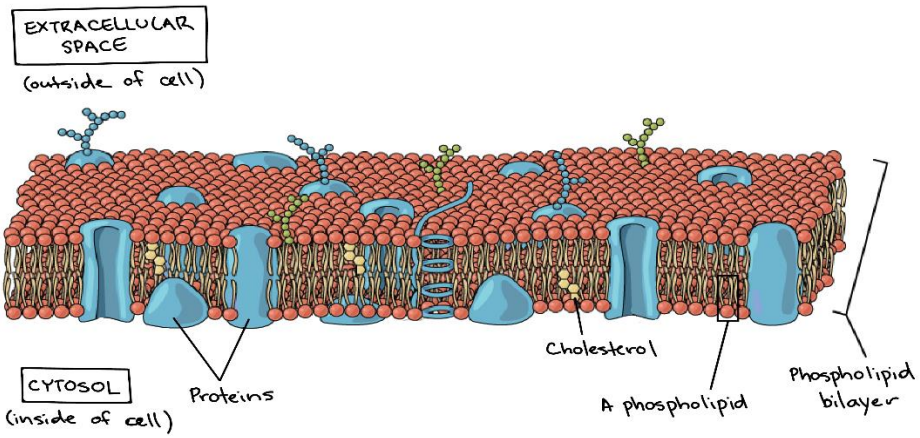
The components of the plasma membrane

Component	Location
Phospholipids	Main fabric of the membrane
Cholesterol	Tucked between the hydrophobic tails of the membrane phospholipids
Integral proteins	Embedded in the phospholipid bilayer; may or may not extend through both layers
Peripheral proteins	On the inner or outer surface of the phospholipid bilayer, but not embedded in its hydrophobic core
Carbohydrates	Attached to proteins or lipids on the extracellular side of the membrane (forming glycoproteins and glycolipids)

Structure

A **phospholipid** is made up of a hydrophilic, water-loving, phosphate head, along with two hydrophobic, water-fearing, fatty acid tails. Phospholipids spontaneously arrange themselves in a double-layered structure with their hydrophobic tails pointing inward and their hydrophilic heads facing outward. This energetically favourable two-layer structure, called a **phospholipid bilayer**, is found in many biological membranes.

As shown below, proteins are also an important component of the plasma membrane. Some of them pass all the way through the membrane, serving as channels or signal receptors, while others are just attached at the edge. Different types of lipids, such as cholesterol, may also be found in the cell membrane and affect its fluidity.



An image of plasma membrane shows the phospholipid bilayer, embedded proteins, and cholesterol molecules. The membrane separates the extracellular space, outside of the cell, from the cytosol inside the cell.

The plasma membrane is the border between the interior and exterior of a cell. As such, it controls passage of various molecules—including sugars, amino acids, ions, and water—into and out of the cell. How easily these molecules can cross the membrane depends on their size and polarity. Some small, nonpolar molecules, such as oxygen, can pass directly through the phospholipid portion of the membrane. Larger and more polar, hydrophilic, molecules, such as amino acids, must instead cross the membrane by way of protein channels, a process that is often regulated by the cell. You can learn more about cellular transport in the membranes and transport section.

The surface area of the plasma membrane limits the exchange of materials between a cell and its environment. Some cells are specialized in the exchange of wastes or nutrients and have modifications to increase the area of the plasma membrane. For instance, the membranes of some nutrient-absorbing cells are folded into finger like projections called **microvilli**, singular, **microvillus**. Cells with microvilli cover the inside surface of the small intestine, the organ that absorbs nutrients from digested food. The microvilli help intestinal cells maximize their absorption of nutrients from food by increasing plasma membrane surface area.
[Microvilli and celiac disease]

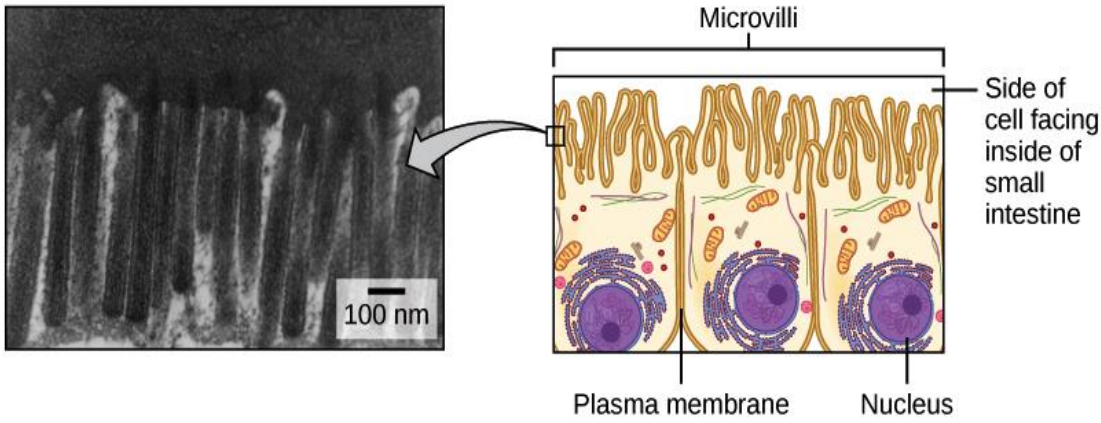


Diagram and micrograph of intestinal cells, showing the protruding "fingers" of plasma membrane—called microvilli—that contact the fluid inside the small intestine.

The cytoplasm

The cytoplasm of a cell is a fluid in nature that fills the cell and is composed mainly of 80% water that also contains enzymes, salts, cell organelles, and various organic molecules.

Cytoplasm was discovered in 1835 and no single scientist can be credited for discovering cytoplasm the discovery was possible due to contribution of several scientists. It is worth mentioning that the discovery of different organelles in the cytoplasm was attributed to different scientist. The cytoplasm is the part of the cell outside the largest organelle, the nucleus. Cytoplasm appears as thick, gel-like semitransparent fluid that is found in both plant and animal cell. It is bounded by the plasma membrane, and contains many organelles in a

eukaryotic cell (cell containing membrane bounded nucleus). The constituent parts of cytoplasm are cytosol, organelles and cytoplasmic inclusions. The cytosol, the aqueous part of the cytoplasm outside all of the organelles, also contains its own distinctive proteins.

Cytosol

Cytosol is the part of the cytoplasm that is not occupied by any organelle. It accounts for almost 70% of the total cell volume. Cytosol (cytoplasmic matrix) like many colloidal systems, shows the property of phase reversal. Under the natural conditions, the phase reversal of the cytosol (cytoplasmic matrix) depends on various physiological, mechanical and biochemical activities of the cell. It is a gelatinous substance consisting mainly of cytoskeleton filaments, organic molecules, salt and water. Chemically, the cytoplasmic matrix is composed of many chemical elements in the form of atoms, ions and molecules. Of the 92 naturally occurring elements, approximately 46 are found in the cytosol (cytoplasmic matrix). Twenty-four of these are essential elements, while others are present in cytosol only because they exist in the environment with which the organism interacts. Of the 24 essential elements, six play especially important roles in living systems. These major elements are carbon (C, 20 per cent), hydrogen (H, 10 per cent), nitrogen (N, 3 per cent), oxygen (O, 62 per cent), phosphorus (P, 1.14 per cent) and sulphur (S,0.14 per cent). Most organic molecules are built with these six elements. Another five essential elements found in less abundance in living systems are calcium (Ca, 2.5 per cent), potassium (K, 0.11 per cent), sodium (Na, 0.10 per cent), chlorine (Cl, 0.16 per cent) and magnesium (Mg, 0.07 per cent).Several other elements, called trace elements, are also found in minute amounts in animal and plant cell cytosol. These are iron (Fe, 0.10 per cent), iodine (I, 0.014 per cent), molybdenum (Mo), manganese (Mn), Cobalt (Co), zinc (Zn), selenium (Se), copper (Cu), chromium (Cr), tin (Sn), vanadium (V), silicon (Si), nickel (Ni), fluorine (F) and boron (B).

The cytoplasmic matrix consists of various kinds of ions. The ions are important in maintaining

osmotic pressure and acid-base balance in the cells. Retention of ions in the matrix produces an increase in osmotic pressure and, thus, the entrance of water in the cell. The concentration of various ions in the intracellular fluid (matrix) differs from that in the interstitial fluid. For example, in the cell K+ and Mg++ can be high, and Na+ and Cl-high outside the cell. In muscle and nerve cells a high order of difference exists between intracellular K+ and extracellular Na+. Free calcium ions (Ca++) may occur in cells or circulating blood. Silicon ions occur in the epithelium cells of grasses.

Chemical compounds present in cytosol are conventionally divided into two groups: organic and inorganic. Organic compounds form 30 per cent of a cell, rest are the inorganic substances such as water and other substances. The inorganic compounds are those compounds which normally found in the bulk of the physical, non-living universe, such as elements, metals, non-metals, and their compounds such as water, salts and variety of electrolytes and non-electrolytes. In the previous section, we have discussed a lot about the inorganic substances except the water which will be discussed in the following paragraph. The main organic compounds of the matrix are the carbohydrates, lipids, proteins, vitamins, hormones and nucleotides.

Properties of cytoplasmic matrix

The most of the physical properties of the matrix are due to its colloidal nature. The cytosol shows Tyndal effect (light scattering by particle in colloidal solution) and Brownian motion (random moving of particles). Due to the phase reversal property of the cytoplasmic matrix, the intracellular streaming or movement of the matrix takes place and is known as the cyclosis. The cyclosis usually occurs in the sol-phase of the matrix and is effected by the hydrostatic pressure, temperature, pH, viscosity, etc. Cyclosis has been observed in most animal and plant cells. The amoeboid movement depends directly on the cyclosis. The amoeboid movement occurs in the protozoans, leucocytes, epithelia, mesenchymal and other cells. Due to cyclosis matrix moves these pseudopodia and this causes forward motion of the cell. The cytoplasmic matrix being a liquid possesses the property of surface tension. The proteins and lipids of matrix have less surface tension, therefore, occur at the surface and form the membrane, while the chemical substances such as NaCl have high surface tension, therefore, occur in deeper part of the matrix. Besides surface tension and adsorption, the matrix possesses other mechanical properties, e.g., elasticity, contractility, rigidity and viscosity which provide to the matrix many physiological utilities. The colloidal system due to its stable phase gives polarity of the cell matrix which cannot be altered by centrifugation of other mechanical means. The matrix has a definite pH value and it does not tolerate significant variations in its pH. Yet various metabolic activities produce small amount of excess acids or bases which is maintained by certain chemical compounds as carbonate-bicarbonate buffers. The matrix is a living substance and possesses various biological properties as irritability, conductivity, movement, metabolic activity, growth and reproduction.

Organelles

Cytoplasm contains all the organelles like nucleus, mitochondria, endoplasmic reticulum, lysosomes and Golgi apparatus. Besides, it also contains chloroplast in plant cells. Each organelle is bounded by a lipid membrane, and has specific functions.

Cytoplasmic inclusions

Some insoluble suspended substances found in cytosol. They are basically granules of starch and glycogen, and they can store energy. Besides, crystals of some minerals and lipid droplets can also be found in cytoplasm. Lipid droplets act as storage site of fatty acid and steroids.

Functions of Cytoplasm

Cytoplasm is the site of many vital biochemical reactions crucial for maintaining life.

1. It is the place where cell expansion and growth take place.

2. It provides a medium in which the organelles can remain suspended.

3. Besides, cytoskeleton found in cytoplasm gives the shape to the cell, and facilitates its movement.

4. It also assists the movement of different elements found within the cell. The enzymes found in the cytoplasm breaks down the macromolecules into small parts so that it can be easily used by the other organelles like mitochondria. For example, mitochondria cannot use glucose

present in the cell, unless it is broken down by the enzymes into pyruvate. They act as catalysts in glycolysis, as well as in the synthesis of fatty acid, sugar and amino acid.

5. Cell reproduction, protein synthesis, anaerobic glycolysis, cytokinesis are some other vital functions that are carried out in cytoplasm. However, the smooth operation of all these functions depend on the existence of cytoplasm, as it provides the medium for carrying out these vital processes.

Chemical components

Chemical components of the cell are

- Water 75-85%
- Protein 10-20%
- Inorganic salts 2-3%
- Monomeric units
- Polymers/macromolecules
- Carbohydrates
- Proteins
- Lipids
- Nucleic acids
- Enzymes

Water

- Water is a good natural medium for dissolving many substances present in a cell
- Water is also in a bound form with proteins participating in hydrogen bonding
- Water has high specific heat coefficient and can absorb heat
- Salts dissociated into anions and cations are important to maintain the acid-base balance and osmotic pressure in a cell.

Carbohydrates

- Carbohydrates are the main sources of energy in living cells
- They are also components of cell wall and intercellular materials
- Monosaccharides are simple sugars triose, pentose, hexose etc
- Glucose is hexose and is important source of energy
- Galactose, fructose and mannose are other hexoses
- Disaccharides areMaltose, Lactose and sucrose
- Polysaccharides are Starch, cellulose and glycogen.

Lipids

- Lipids are relatively less soluble in water and soluble in organic solvents. Simple lipids are esters of fatty acids.
- Natural fats are triglycerides that are triesters of fatty acids and glycerol.
- Triglycerides are used as storage forms of energy in adipose tissues
- The energy is derived from the oxidation of fatty acids.

• Compound lipids are more complex and yield many components upon hydrolysis other than fatty acids and alcohol. They are important components of cell membrane.

• Phospholipids are important components of the cell membrane. They have two fatty acids esterified with glycerol and the hydroxyl group of glycerol is esterified with phosphoric acid bound with choline or ethanolamine or serine or inositol.

Proteins

• Amino acids are the building blocks of proteins.

• There are 20 different types of amino acids present in proteins.

• Primary structures of proteins are characterized by the sequence of aminoacids.

• Secondary structure is by the formation of alpha helix or beta pleated sheet stabilized by the hydrogen bonds.

• Other segments of a protein can adopt to a random coil structure.

• Tertiary structure refers to the 3-dimensional arrangements as globulins or fibrous proteins.

• Quaternary structure is the arrangement of protein subunits.

• Enzymes are also proteins and act as biocatalysts.

DNA and RNA

• Nucleic acids are made up of bases, sugars and phosphates

• Deoxy ribose in DNA and ribose in RNA

• The bases are Adenine, Thymine, Cytosine and Guanine in DNA

• The bases in RNA are Adenine, Uracil, Cytosine and Guanine

• Adenine and Guanine are purines

• Cytosine, Uracil and Thymine are pyrimidines

• Nucleotides are linked together by phosphodiester linkages

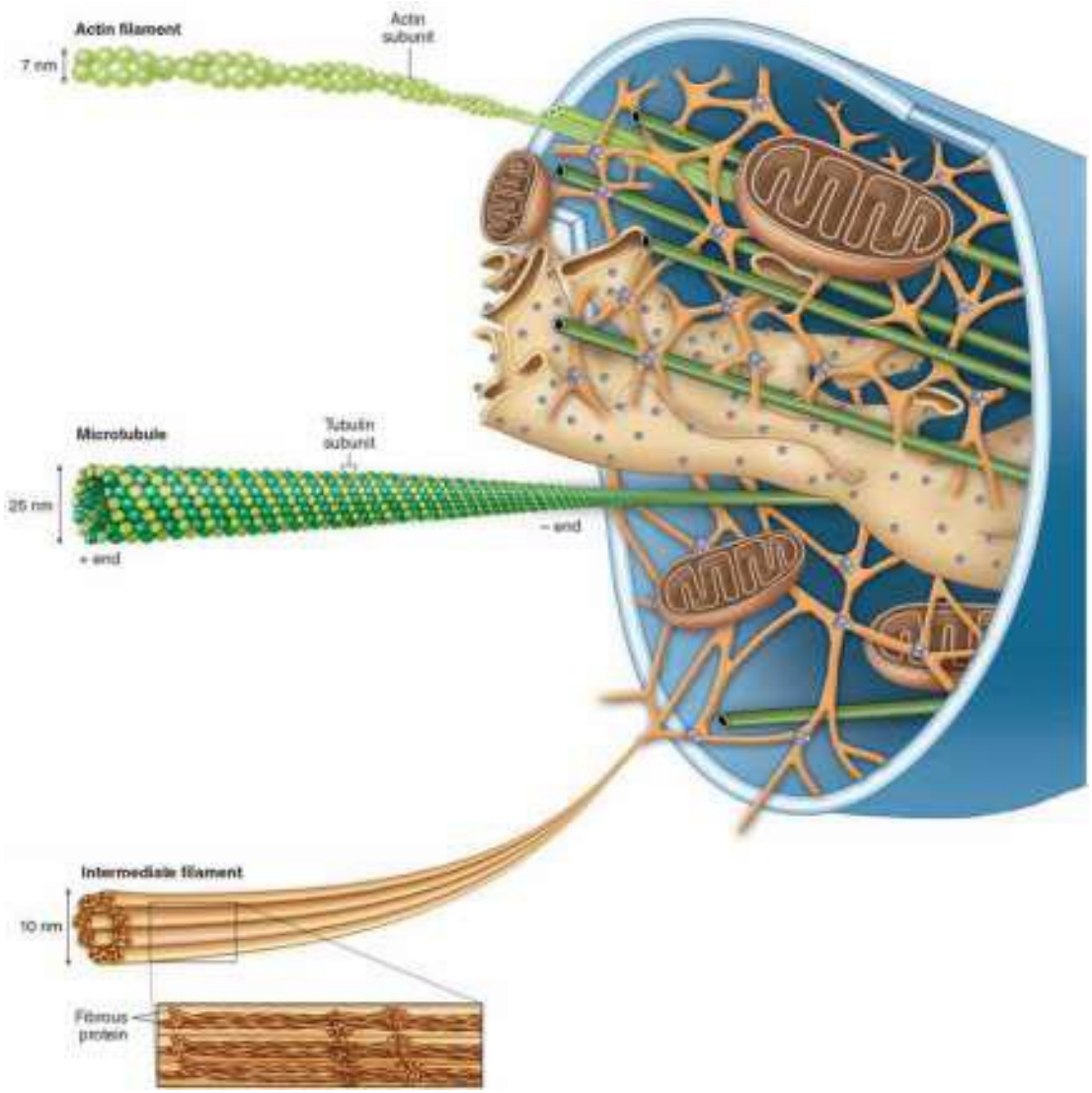
• Nucleotides such as ATP are important to store and transfer chemical energy in a cell.

The cytoskeleton

Introduction

Cells have a network of filaments known as the cytoskeleton (literally, “cell skeleton”), which not only supports the plasma membrane and gives the cell an overall shape, but also aids in the correct positioning of organelles, provides tracks for the transport of vesicles, and (in many cell types) allows the cell to move.

In eukaryotes, there are three types of protein fibers in the cytoskeleton: microfilaments, intermediate filaments, and microtubules. Here, we'll examine each type of filament, as well as some specialized structures related to the cytoskeleton.



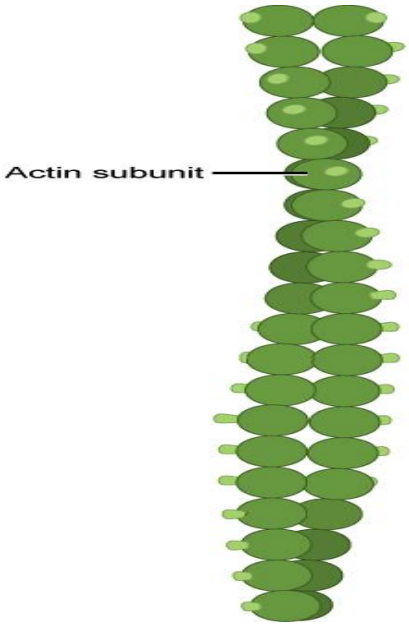
Microfilaments

Of the three types of protein fibers in the cytoskeleton, **microfilaments** are the narrowest. They have a diameter of about 7 nm and are made up of many linked monomers of a protein called actin, combined in a structure that resembles a double helix. Because they are made of actin monomers, microfilaments are also known as **actin filaments**. Actin filaments have directionality, meaning that they have two structurally different ends.

Actin filaments have a number of important roles in the cell. For one, they serve as tracks for the movement of a motor protein called **myosin**, which can also form filaments. Because of its relationship to myosin, actin is involved in many cellular events requiring motion.

For instance, in animal cell division, a ring made of actin and myosin pinches the cell apart to generate two new daughter cells. Actin and myosin are also plentiful in muscle cells, where they form organized structures of overlapping filaments called sarcomeres. When the actin and myosin filaments of a sarcomere slide past each other in concert, your muscles contract.

Actin filaments may also serve as highways inside the cell for the transport of cargoes, including protein-containing vesicles and even organelles. These cargoes are carried by individual myosin motors, which "walk" along actin filament bundles^11start superscript, 1, end superscript.



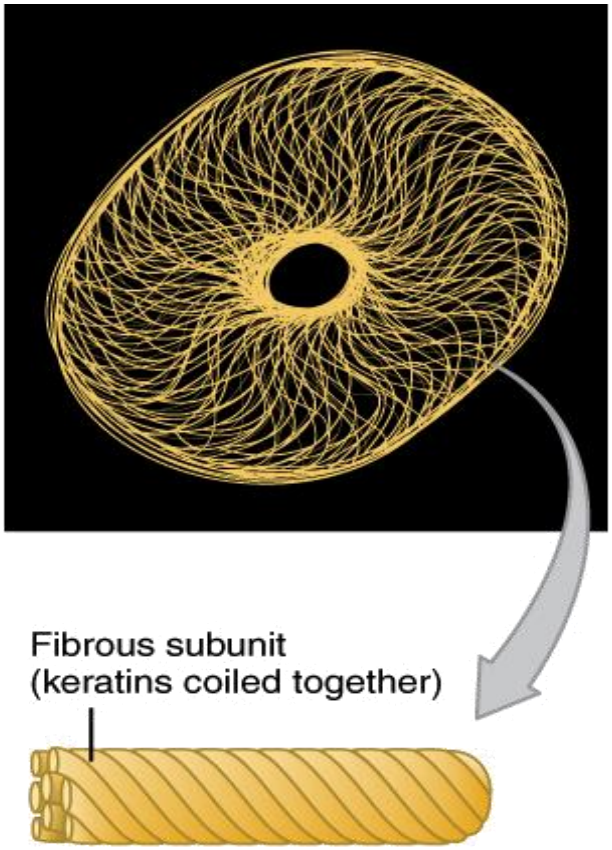
Actin filament, a double helix-like structure made out of actin monomers (subunits).

Actin filaments can assemble and disassemble quickly, and this property allows them to play an important role in cell motility (movement), such as the crawling of a white blood cell in your immune system.

Finally, actin filaments play key structural roles in the cell. In most animal cells, a network of actin filaments is found in the region of cytoplasm at the very edge of the cell. This network, which is linked to the plasma membrane by special connector proteins, gives the cell shape and structure.

Intermediate filaments

Intermediate filaments are a type of cytoskeletal element made of multiple strands of fibrous proteins wound together. As their name suggests, intermediate filaments have an average diameter of 8 to 10 nm, in between that of microfilaments and microtubules



Intermediate filaments in a cell, forming a network that holds the nucleus and other organelles in place.

Intermediate filaments come in a number of different varieties, each one made up of a different type of protein. One protein that forms intermediate filaments is keratin, a fibrous protein found in hair, nails, and skin. For instance, you may have seen shampoo ads that claim to smooth the keratin in your hair!

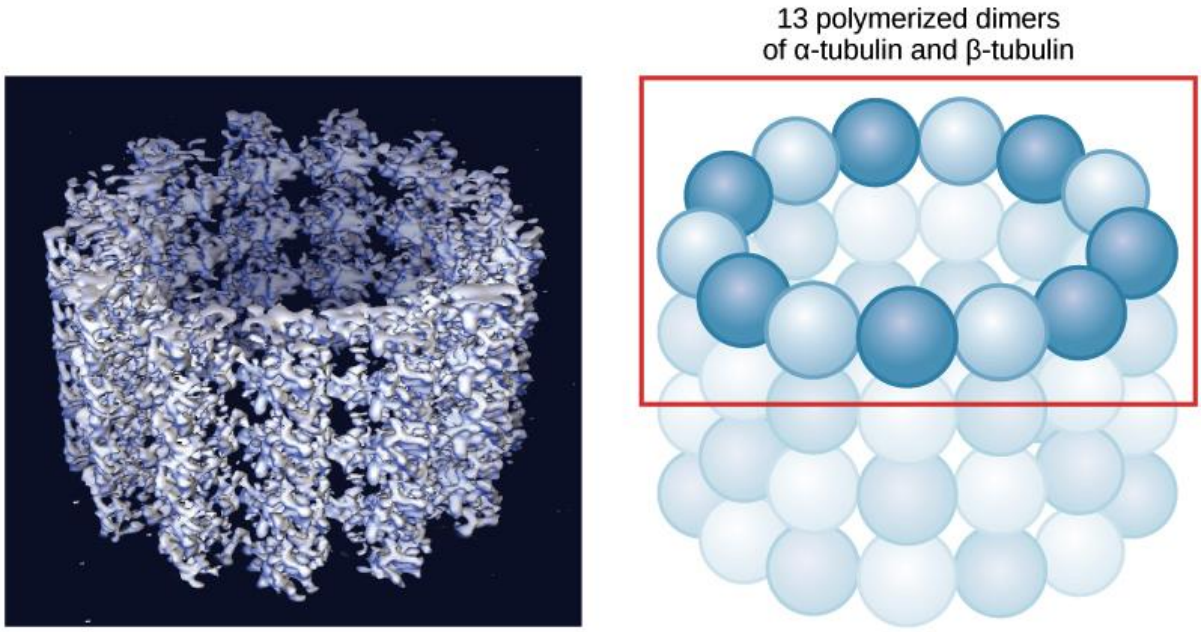
Unlike actin filaments, which can grow and disassemble quickly, intermediate filaments are more permanent and play an essentially structural role in the cell. They are specialized to bear tension, and their jobs include maintaining the shape of the cell and anchoring the nucleus and other organelles in place.

Microtubules

Despite the "micro" in their name, **microtubules** are the largest of the three types of cytoskeletal fibers, with a diameter of about 25 nm. A microtubule is made up of tubulin proteins arranged to form a hollow, straw-like tube, and each tubulin protein consists of two subunits, α-tubulin and β-tubulin.

Microtubules, like actin filaments, are dynamic structures: they can grow and shrink quickly by the addition or removal of tubulin proteins. Also similar to actin filaments, microtubules have directionality, meaning that they have two ends that are structurally different from one another. In a cell, microtubules play an important structural role, helping the cell resist compression forces.

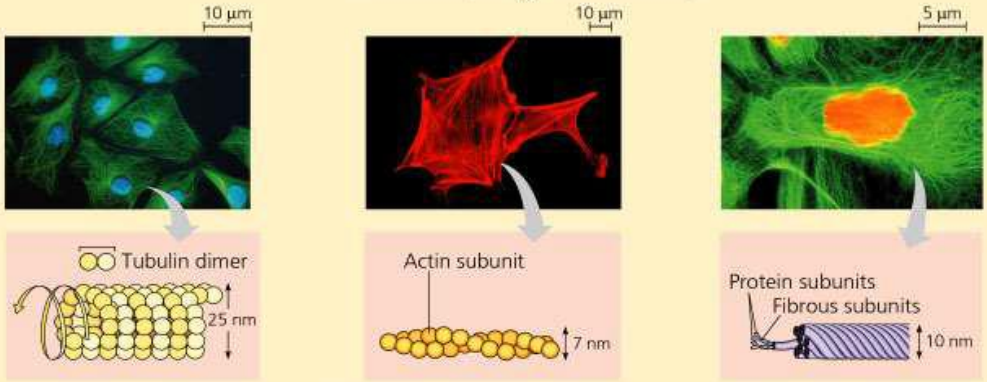
In addition to providing structural support, microtubules play a variety of more specialized roles in a cell. For instance, they provide tracks for motor proteins called kinesins and dyneins, which transport vesicles and other cargoes around the interior of the cell. During cell division, microtubules assemble into a structure called the spindle, which pulls the chromosomes apart.



Left: 3D model of a microtubule, showing that it is a hollow cylinder of proteins. Right: Cartoon diagram of a microtubule, showing that it is made of two different types of subunits (alpha and beta). The subunits form dimers, and the dimers are connected in a spiral pattern to form the hollow tube of the microtubule.

Table 7.2 The Structure and Function of the Cytoskeleton

Property	Microtubules	Microfilaments (Actin Filaments)	Intermediate Filaments
Structure	Hollow tubes; wall consists of 13 columns of tubulin molecules	Two intertwined strands of actin	Fibrous proteins supercoiled into thicker cables
Diameter	25 nm with 15-nm lumen	7 nm	8–12 nm
Protein subunits	Tubulin, consisting of α-tubulin and β-tubulin	Actin	One of several different proteins of the keratin family, depending on cell type
Main functions	Maintenance of cell shape (compression-resisting "girders") Cell motility (as in cilia or flagella) Chromosome movements in cell division Organelle movements	Maintenance of cell shape (tension-bearing elements) Changes in cell shape Muscle contraction Cytoplasmic streaming Cell motility (as in pseudopodia) Cell division (cleavage furrow formation)	Maintenance of cell shape (tension-bearing elements) Anchorage of nucleus and certain other organelles Formation of nuclear lamina



SOURCE: Adapted from W. M. Becker, L. J. Kleinsmith, and J. Hardin, *The World of the Cell*, 4th ed. (San Francisco, CA: Benjamin Cummings, 2000), p. 753.

The endomembrane system

The **endomembrane system** (*endo-* = "within") is a group of membranes and organelles in eukaryotic cells that works together to modify, package, and transport lipids and proteins. It includes a variety of organelles, such as the nuclear envelope and lysosomes, which you may already know, and the endoplasmic reticulum and Golgi apparatus, which we will cover shortly.

Although it's not technically inside the cell, the plasma membrane is also part of the endomembrane system. As we'll see, the plasma membrane interacts with the other endomembrane organelles, and it's the site where secreted proteins (like the pancreatic enzymes in the intro) are exported. Important note: the endomembrane system does not include mitochondria, chloroplasts, or peroxisomes.

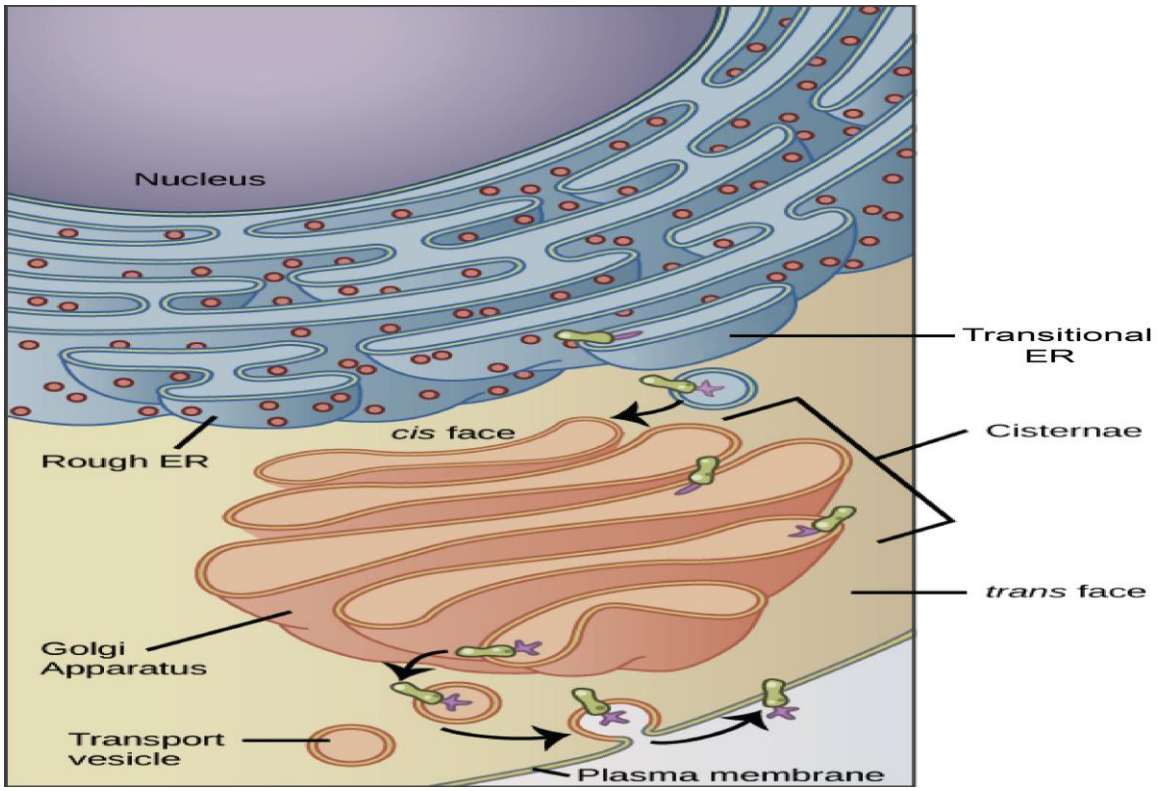


Image showing transport of a membrane protein from the rough ER through the Golgi to the plasma membrane. The protein is initially modified by the addition of branching carbohydrate chains in the rough ER; these chains are then trimmed back and replaced with other branching chains in the Golgi apparatus. The protein, with its final set of carbohydrate chains, is then transported to the plasma membrane in a transport vesicle. The vesicle fuses with the plasma membrane, its lipids and protein cargo becoming part of the plasma membrane.

The endoplasmic reticulum

The **endoplasmic reticulum** (**ER**) plays a key role in the modification of proteins and the synthesis of lipids. It consists of a network of membranous tubules and flattened sacs. The discs and tubules of the ER are hollow, and the space inside is called the **lumen**.

Morphology:

The endoplasmic reticulum occurs in three forms: 1. Lamellar form or cisternae which is a closed, fluid-filled sac, vesicle or cavity is called cisternae; 2. vesicular form or vesicle and 3. tubular form or tubules.

1. Cisternae: The cisternae are long, flattened, sac-like, unbranched tubules having diameter of 40 to 50 µm. They remain arranged parallely in bundles or stakes. RER mostly exists as cisternae which occur in those cells which have synthetic roles as the cells of pancreas, notochord and brain.

2. Vesicles: The vesicles are oval, membrane-bound vacuolar structures having diameter of 25 to 500 µm. They often remain isolated in the cytoplasm and occur in most cells but especially abundant in the SER.

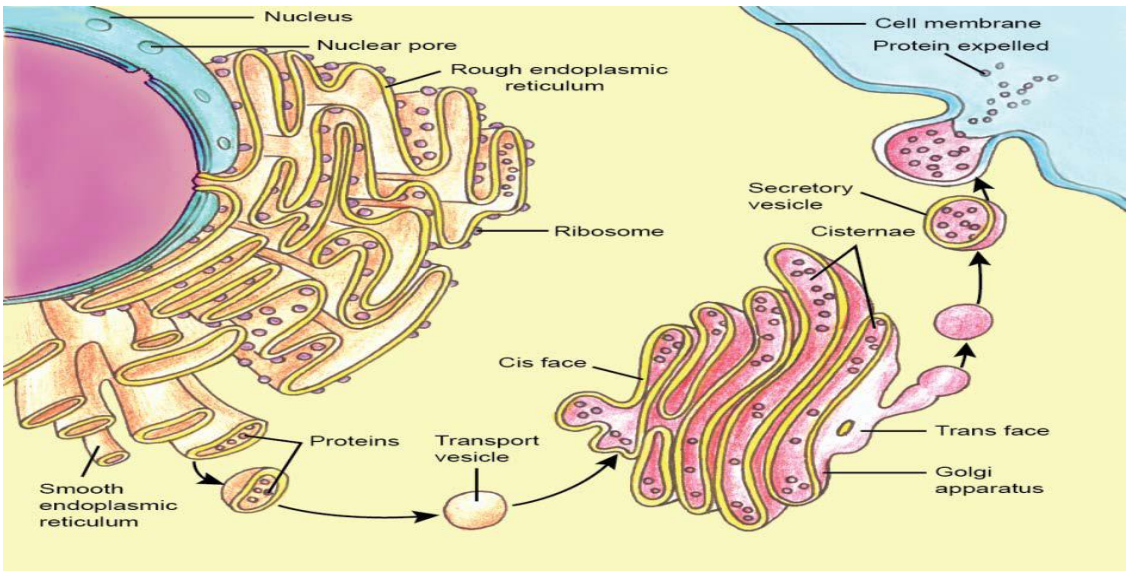
3. Tubules: The tubules are branched structures forming the reticular system along with the cisternae and vesicles. They usually have the diameter from 50 to 190 µm and occur almost in all the cells. Tubular form of ER is often found in SER and is dynamic in nature, *i.e.*, it is associated with membrane movements, fission and fusion between membranes of cytocavity network.

Rough ER

The **rough endoplasmic reticulum** (**rough ER**) gets its name from the bumpy ribosomes attached to its cytoplasmic surface. As these ribosomes make proteins, they feed the newly forming protein chains into the lumen. Some are transferred fully into the ER and float inside, while others are anchored in the membrane.

Inside the ER, the proteins fold and undergo modifications, such as the addition of carbohydrate side chains. These modified proteins will be incorporated into cellular membranes—the membrane of the ER or those of other organelles—or secreted from the cell.

If the modified proteins are not destined to stay in the ER, they will be packaged into **vesicles**, or small spheres of membrane that are used for transport, and shipped to the Golgi apparatus. The rough ER also makes phospholipids for other cellular membranes, which are transported when the vesicle forms.



The Endoplasmic reticulum.

Since the rough ER helps modify proteins that will be secreted from the cell, cells whose job is to secrete large amounts of enzymes or other proteins, such as liver cells, have lots of rough ER.

Smooth ER

The **smooth endoplasmic reticulum** (**smooth ER**) is continuous with the rough ER but has few or no ribosomes on its cytoplasmic surface. Functions of the smooth ER include:

- Synthesis of carbohydrates, lipids, and steroid hormones
- Detoxification of medications and poisons
- Storage of calcium ions

In muscle cells, a special type of smooth ER called the sarcoplasmic reticulum is responsible for storage of calcium ions that are needed to trigger the coordinated contractions of the muscle cells.

There are also tiny "smooth" patches of ER found within the rough ER. These patches serve as exit sites for vesicles budding off from the rough ER and are called **transitional ER**.

Functions of SER And RER:

1. The endoplasmic reticulum provides an ultrastructural skeletal framework to the cell and gives mechanical support to the colloidal cytoplasmic matrix.
2. The exchange of molecules by the process of osmosis, diffusion and active transport occurs through the membranes of endoplasmic reticulum. The ER membrane has permeases and carriers.
3. The endoplasmic membranes contain many enzymes which perform various synthetic and metabolic activities and provides increased surface for various enzymatic reactions.
4. The endoplasmic reticulum acts as an intracellular circulatory or transporting system. Various secretory products of granular endoplasmic reticulum are transported to various organelles as follows: Granular ER− agranular ER − Golgi membrane−lysosomes, transport vesicles or secretory granules. Membrane flow may also be an important mechanism for carrying particles, molecules and ions into and out of the cells. Export of RNA and nucleoproteins from nucleus to cytoplasm may also occur by this type of flow.
5. The ER membranes are found to conduct intra-cellular impulses. For example, the sarcoplasmic reticulum transmits impulses from the surface membrane into the deep region of the muscle fibres.
6. The sarcoplasmic reticulum plays a role in releasing calcium when the muscle is stimulated and actively transporting calcium back into the sarcoplasmic reticulum when the stimulation stops and the muscle must be relaxed.

The Golgi apparatus

The Golgi complex was discovered by Camillo Golgi during an investigation of the nervous system and he named it the “internal reticular apparatus”. Functionally it is also known as the

post office of the cell. Certain important cellular functions such as biosynthesis of polysaccharides, packaging (compartmentalizing) of cellular synthetic products (proteins), production of exocytotic (secretory) vesicles and differentiation of cellular membranes, occurs in the Golgi complex or Golgi apparatus located in the cytoplasm of animal and plant cells.

Occurrence:

The Golgi apparatus occurs in all eukaryotic cells. The exceptions are the prokaryotic cells (mycoplasmas, bacteria and blue green algae) and eukaryotic cells of certain fungi, sperm cells of bryophytes and pteridiophytes, cells of mature sieve tubes of plants and mature sperm and red blood cells of animals. Their number per plant cell can vary from several hundred as in tissues of corn root and algal rhizoids (*i.e*., more than 25,000 in algal rhizoids, Sievers,1965), to a single organelle in some algae. In higher plants, Golgi apparatuses are particularly common in secretory cells and in young rapidly growing cells. In animal cells, there usually occurs a single Golgi apparatus, however, its number may vary from animal to animal and from cell to cell. *Paramoeba* species has two golgi apparatuses and nerve cells, liver cells and chordate oocytes have multiple golgi apparatuses, there being about 50 of them in the liver cells.

Morphology

The Golgi apparatus is morphologically very similar in both plant and animal cells. However, it is extremely pleomorphic: in some cell types it appears compact and limited, in others spread out and reticular (net-like). Its shape and form may vary depending on cell type. It appears as a complex array of interconnecting tubules, vesicles and cisternae. There has been much debate concerning the terminology of the Golgi's parts. The simplest unit of the Golgi apparatus is the cisterna. This is a membrane bound space in which various materials and secretions may accumulate. Numerous cisternae are associated with each other and appear in a stack-like (lamellar) aggregation. A group of these cisternae is called the dictyosome, and a group of dictyosomes makes up the cell's Golgi apparatus. All dictyosomes of a cell have a common function. The detailed structure of three basic components of the Golgi apparatus are as follows:

1. Flattened Sac or Cisternae

Cisternae of the golgi apparatus are about 1 μm in diameter, flattened, plate-like or saucer-like closed compartments which are held in parallel bundles or stacks one above the other. In each stack, cisternae are separated by a space of 20 to 30 nm which may contain rod-like elements or fibres. Each stack of cisternae forms a dictyosome which may contain 5 to 6 Golgi cisternae in animal cells or 20 or more cisternae in plant cells. Each cisterna is bounded by a smooth unit membrane (7.5 nm thick), having a lumen varying in width from about 500 to 1000 nm. Polarity. The margins of each cisterna are gently curved so that the entire dictyosome of Golgi apparatus takes on a bow-like appearance. The cisternae at the convex end of the dictyosome comprise proximal, forming or cis-face and the cisternae at the concave end of the dictyosome comprise the distal, maturing or trans-face. The forming or cis face of Golgi is located next to either the nucleus or a specialized portion of rough ER that lacks bound ribosomes and is called "transitional" ER. Trans face of Golgi is located near the plasma membrane. This polarization is called cis-trans axis of the Golgi apparatus.

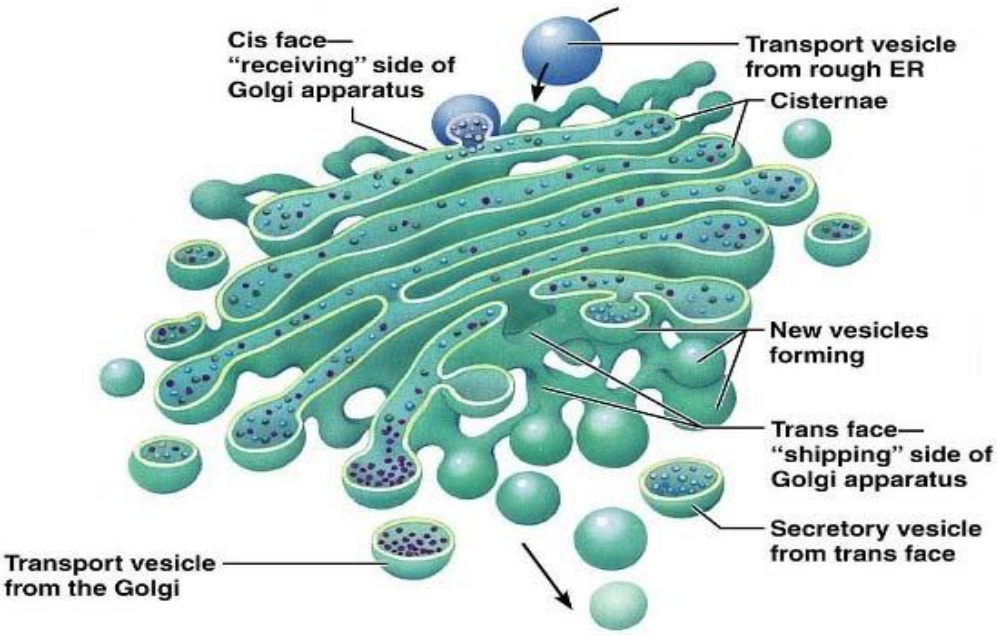
2. Tubules

A complex array of associated vesicles and tubules (30 to 50 nm diameter) surround the dictyosome and radiate from it. The peripheral area of dictyosome is fenestrated or lace-like in structure.

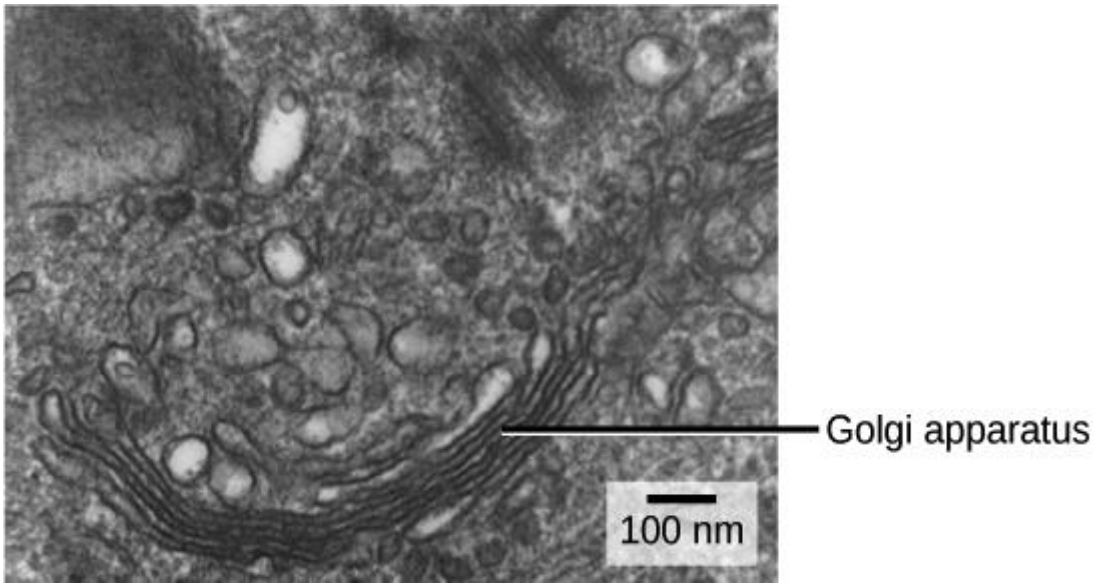
3. Vesicles

The vesicles are 60 nm in diameter and are of three types : (i) Transitional vesicles are small membrane limited vesicles which are form as blebs from the transitional ER to migrate and converge to cis face of Golgi, where they coalasce to form new cisternae.

(ii) Secretory vesicles are varied-sized membrane-limited vesicles which discharge from margins of cisternae of Golgi. They, often, occur between the maturing face of Golgi and the plasma membrane.



Golgi apparatus



Micrograph of the Golgi apparatus showing a series of flattened membrane discs in cross-section

Functions:

1. Modifying, sorting, and packaging of macromolecules for cell secretion: The golgi complex is involved in the transport of lipids around the cell, and the creation of lysosomes. Proteins are modified by enzymes in cisternae by glycosylation and phosphorylation by identifying the signal sequence of the protein in question. For example, the Golgi apparatus adds a mannose-6-phosphate label to proteins destined for lysosomes. One molecule that is phosphorylated in the Golgi is Apolipoprotein, which forms a molecule known as VLDL that is a constituent of blood serum. The phosphorylation of these molecules is important to help aid in their sorting for secretion into the blood serum.

2. **Proteoglycans and carbohydrate synthesis**: This includes the production of glycosaminoglycans (GAGs), long unbranched polysaccharides which the Golgi then attaches to a protein synthesised in the endoplasmic reticulum to form proteoglycans.

3. **Golgi Functions in Animals:**

In animals, Golgi apparatus is involved in the packaging and exocytosis of the following: Zymogen of exocrine pancreatic cells; Mucus (a glycoprotein) secretion by goblet cells of intestine; Lactoprotein (casein) secretion by mammary gland cells (Merocrine secretion); Secretion of compounds (thyroglobulins) of thyroxine hormone by thyroid cells; Secretion of tropocollagen and collagen; Formation of melanin granules and other pigments; and Formation of yolk and vitelline membrane of growing primary oocytes. It is also involved in the formation of certain cellular organelles such as plasma membrane, lysosomes, acrosome of spermatozoa and cortical granules of a variety of oocytes.

4. **Golgi Functions in Plants**:

In plants, Golgi apparatus is mainly involved in the secretion of materials of primary and secondary cell walls (formation and export of glycoproteins, lipids, pectins and monomers for hemicellulose, cellulose, lignin). During cytokinesis of mitosis or meiosis, the vesicles originating from the periphery of Golgi apparatus, coalesce in the phragmoplast area to form a semisolid layer, called cell plate. The unit membrane of Golgi vesicles fuses during cell plate formation and becomes part of plasma membrane of daughter

Lysosomes

The **lysosome** is an organelle that contains digestive enzymes and acts as the organelle-recycling facility of an animal cell. It breaks down old and unnecessary structures so their molecules can be reused. Lysosomes are part of the endomembrane system, and some vesicles that leave the Golgi are bound for the lysosome.

Introduction:

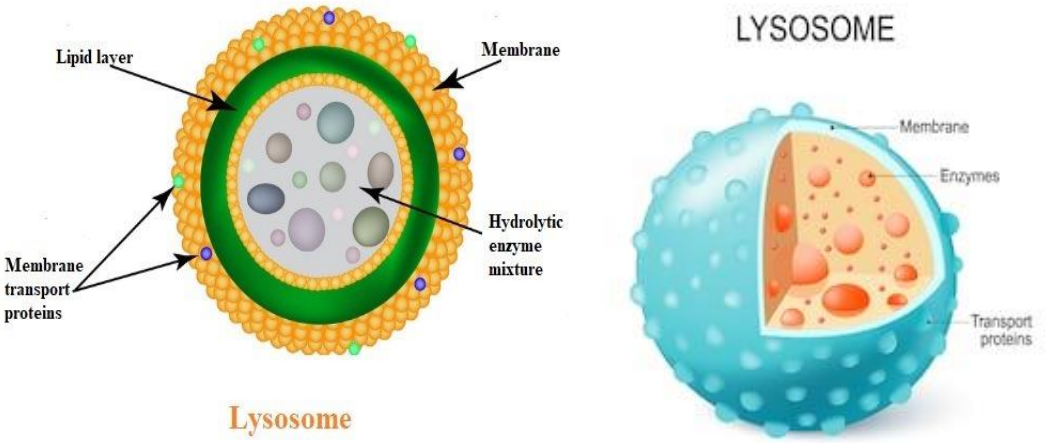
C. de Duve, in 1955, named these organelles as ‘lysosomes’. Lysosomes is an organelle which provides an excellent example of the ability of intracellular membranes to form closed compartments in which the composition of the lumen (the aqueous interior of the compartment)

differs substantially from that of the surrounding cytosol. Found exclusively in animal cells, lysosomes are responsible for degrading certain components that have become obsolete for the cell or organism. Lysosomes are often budded from the membrane of the Golgi apparatus, but in some cases, they develop gradually from late endosomes, which are vesicles that carry materials brought into the cell by a process known as endocytosis. The biogenesis of the lysosomes requires the synthesis of specialized lysosomal hydrolases and membrane proteins. Both classes of proteins are synthesized in the ER and transported through the Golgi apparatus, then transported from the trans Golgi network to an intermediate compartment (an endolysosome) by means of transport vesicles (which are coated by clathrin protein).

Occurrence:

The lysosomes occur in most animal and few plant cells. They are absent in bacteria and mature mammalian erythrocytes. Few lysosomes occur in muscle cells or in acinar cells of the pancreas. Leucocytes, especially granulocytes are a particularly rich source of lysosomes. Their lysosomes are so large-sized that they can be observed under the light microscope. They are also numerous in epithelial cells of absorptive, secretory and excretory organs (intestine, liver, and kidney). They occur in abundance in the epithelial cells of lungs and uterus. Phagocytic cells and cells of reticuloendothelial system (bone marrow, spleen and liver) are also rich in lysosomes.

Structure:

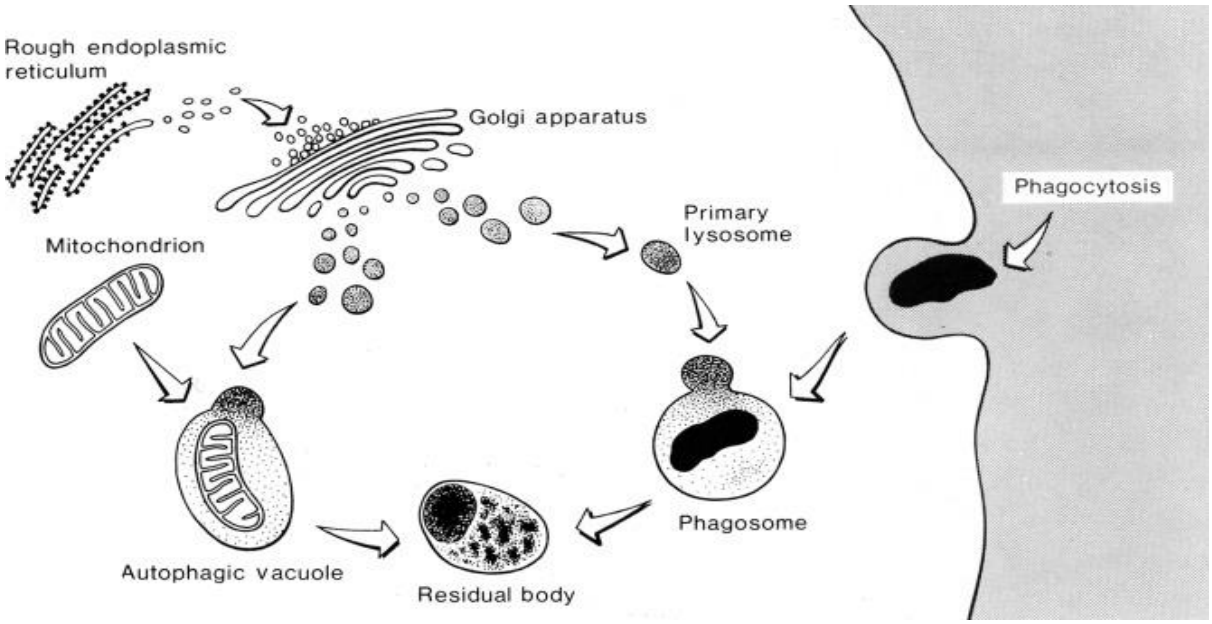


The lysosomes are round vacuolar structures bounded by single unit membrane. Their shape and density vary greatly. Lysosomes are 0.2 to 0.5µm in size. Since, size and shape of lysosomes vary from cell to cell and time to time (they are polymorphic), their identification becomes difficult.

Functions:

1. Lysosomes serve as digestion compartments for cellular materials that have exceeded their lifetime or are otherwise no longer useful by autophagy. When a cell dies, the lysosome membrane ruptures and enzymes are liberated. These enzymes digest the dead cells. In the process of metamorphosis of amphibians and tunicates many embryonic tissues,
e.g., gills, fins, tail, etc., are digested by the lysosomes and utilized by the other cells.

2. Lysosomes break down cellular waste products, fats, carbohydrates, proteins, and other macromolecules into simple compounds, which are then transferred back into the cytoplasm as new cell-building materials. To accomplish the tasks associated with digestion, the lysosomes utilize about 40 different types of hydrolytic enzymes, all of which are manufactured in the endoplasmic reticulum and modified in the Golgi apparatus.
3. Digestion of large extracellular particles: The lysosomes digest the food contents of the phagosomes or pinosomes. The lysosomes of leucocytes enable the latter to devour the foreign proteins, bacteria and viruses.

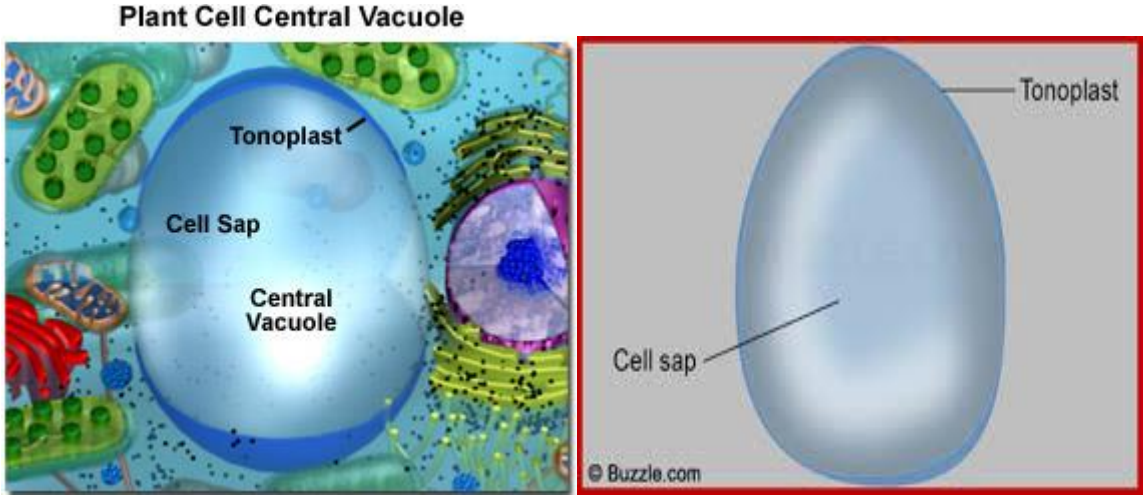


4. Extracellular digestion: The lysosomes of certain cells such as sperms discharge their enzymes outside the cell during the process of fertilization. The lysosomal enzymes digest the limiting membranes of the ovum and form penetra path in ovum for the sperms. Acid hydrolases are released from osteoclasts and break down bone for the reabsorption; these cells also secrete lactic acid which makes the local pH enough for optimal enzyme activity. Likewise, preceding ossification (bone formation), fibroblasts release cathepsin D enzyme to break down the connective tissue.

Vacuoles

The most conspicuous compartment in most plant cells is a very large, fluid-filled vesicle called a vacuole. There may be several vacuoles in a single cell, each separated from the cytoplasm by a single unit membrane, called the tonoplast. Generally, vacuoles occupy more than 30 per cent of the cell volume; but this may vary from 5 per cent to 90 per cent, depending on the cell type. Plant cell vacuoles are widely diverse in form, size, content, and functional dynamics, and a single cell may contain more than one kind of vacuole. Most plant cells contain at least one membrane limited internal vacuole. The number and size of vacuoles depend on both the type of cell and its stage of development; a single vacuole may occupy as much as 80 percent of a mature plant cell. They are lytic compartments, function as reservoirs for ions and

metabolites, including pigments, and are crucial to processes of detoxification and general cell homeostasis. They are involved in cellular responses to environmental and biotic factors that provoke stress. A variety of transport proteins in the vacuolar membrane allow plant cells to accumulate and store water, ions, and nutrients (sucrose, amino acids) within vacuoles. Like a lysosome, the lumen of a vacuole contains a battery of degradative enzymes and has an acidic pH, which is maintained by similar transport proteins in the vacuolar membrane. Plant vacuoles may also have a degradative function similar to that of lysosomes in animal cells. Similar storage vacuoles are found in green algae and many microorganisms such as fungi. Like most cellular membranes, the vacuolar membrane is permeable to water but is poorly permeable to the small molecules stored within it. Because the solute concentration is much higher in the vacuole lumen than in the cytosol or extracellular fluids, water tends to move by osmotic flow into vacuoles, just as it moves into cells placed in a hypotonic medium. This influx of water causes both the vacuole to expand and water to move into the cell, creating hydrostatic pressure, or turgor, inside the cell. This pressure is balanced by the mechanical resistance of the cellulose-containing cell walls that surround plant cells. Most plant cells have a turgor of 5–20 atmospheres (atm); their cell walls must be strong enough to react to this pressure in a controlled way. Unlike animal cells, plant cells can elongate extremely rapidly, at rates of 20–75 μm/h. This elongation, which usually accompanies plant growth, occurs when a segment of the somewhat elastic cell wall stretches under the pressure created by water taken into the vacuole. The central vacuole in plant cells (Figure 5) is bounded by a membrane termed the tonoplast which is an important constituent of the plant endomembrane system. This vacuole develops as the cell matures by fusion of smaller vacuoles derived from the endoplasmic reticulum and Golgi apparatus. Functionally it is highly selective in transporting materials through its membrane. The cell sap inside the vacuole differs from the cytoplasm.



Functions:

1. Vacuoles often store the pigments that give flowers their colors, which aid them in the attraction of bees and other pollinators.

2. It can also be comprised of plant wastes that while developing seed cells use the central vacuole as a repository for protein storage.

3. The central vacuole also is responsible for salts, minerals, nutrients, proteins and pigments storage which in turn helps in plant growth, and plays an important structural role for the plant.

4. Vacuoles are also important for maintaining turgor pressure which controls the rigidity of the cell. Due to the process of osmosis when a plant receives large amounts of water, the central vacuoles of the cell swell as the liquid enters within them, increasing turgor pressure, which helps maintain the structural integrity of the plant, along with the support from the cell wall. In the absence of enough water, however, central vacuoles shrink and turgor pressure is reduced, compromising the plant's rigidity and wilting takes place.

5. Plant vacuoles are also important for their role in molecular degradation and storage. Sometimes these functions are carried out by different vacuoles in the same cell, one serving as a compartment for breaking down materials (similar to the lysosomes found in animal cells), and another storing nutrients, waste products, or other substances. Several of the materials commonly stored in plant vacuoles have been found to be useful for humans, such as opium, rubber, and garlic flavoring, and are frequently harvested.

6. Sometimes Vacuoles contain molecules that are poisonous, odoriferous, or unpalatable to various insects and animals.

Peroxisomes

All animal cells (except erythrocytes) and most plant cells contain peroxisomes. They are present in all photosynthetic cells of higher plants in etiolated leaf tissue, in coleoptiles and hypocotyls, in tobacco stem and callus, in ripening pear fruits and also in Euglenophyta, Protozoa, brown algae, fungi, liverworts, mosses and ferns. Peroxisomes contain several oxidases.

Structure:

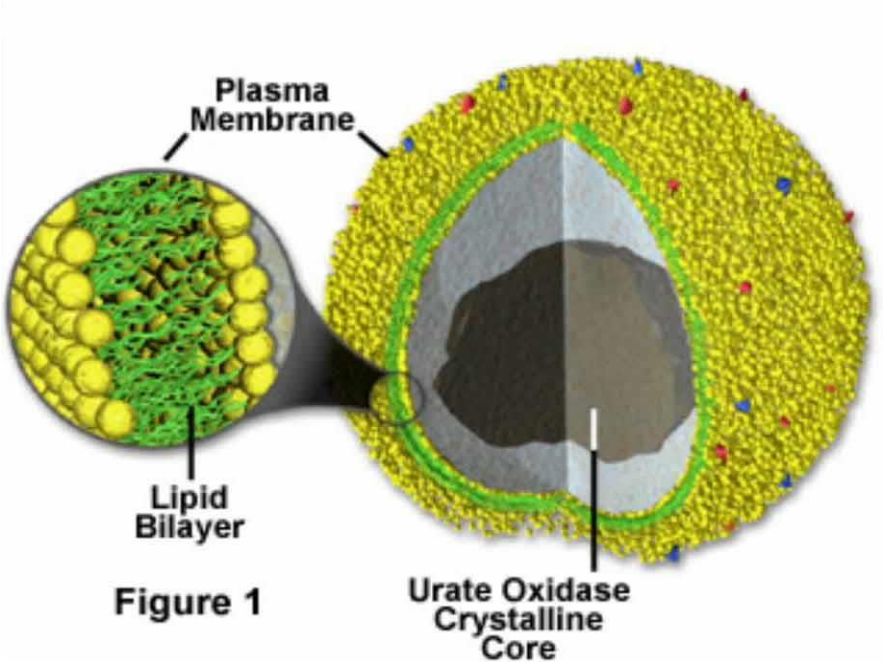


Figure 1

Peroxisomes are variable in size and shape, but usually appear circular in cross section having

diameter between 0.2 and 1.5μm. They have a single limiting unit membrane of lipid and protein molecules, which encloses their granular matrix. Like mitochondria and chloroplasts, they acquire their proteins by selective import from the cytosol. Peroxisomes resemble the Endoplasmic reticulum by being self-replicating, membrane-enclosed organelle that exists without a genome of its own.

Peroxisomes are unusually diverse organelles, and even in the various cell types of a single organism they may contain different sets of enzymes. They can also adapt remarkably to changing conditions. Yeast cells grown on sugar, for example, have small peroxisomes. But when some yeasts are grown on methanol, they develop large peroxisomes that oxidize methanol; and when grown on fatty acids, they develop large peroxisomes that break down fatty acids to acetyl CoA by β oxidation. Peroxisomes are also important in plants. Two different types have been studied extensively. One type is present in leaves, where it catalyzes the oxidation of a side product of the crucial reaction that fixes CO2 in carbohydrate. This process is called photorespiration because it uses up O2 and liberates CO2. The other type of peroxisome is present in germinating seeds, where it has an essential role in converting the fatty acids stored in seed lipids into the sugars needed for the growth of the young plant. Because this conversion of fats to sugars is accomplished by a series of reactions known as the glyoxylate cycle, these peroxisomes are also called glyoxysomes. In the glyoxylate cycle, two molecules of acetyl CoA produced by fatty acid breakdown in the peroxisome are used to make succinic acid, which then leaves the peroxisome and is converted into glucose. The glyoxylate cycle does not occur in animal cells, and animals are therefore unable to convert the fatty acids in fats into carbohydrates. Glyoxysomes occur in the cells of yeast, Neurospora, and oil rich seeds of many higher plants. They resemble with peroxisomes in morphological details, except that, their crystalloid core consists of dense rods of 6.0 μm diameter.

Chemical composition:

Internally peroxisomes contain several oxidases like catalase and urate oxidase-enzymes that use molecular oxygen to oxidize organic substances, in the process forming hydrogen peroxide (H2O2), a corrosive substance. Catalase is present in large amounts and degrades hydrogen peroxide to yield water and oxygen.

A specific sequence of three amino acids located at the C-terminus of many peroxisomal proteins functions as an import signal. Other peroxisomal proteins contain a signal sequence near the N terminus. If either of these sequences is experimentally attached to a cytosolic protein, the protein is imported into peroxisomes. The import process is yet to be understood completely, although it is known to involve soluble receptor proteins in the cytosol that recognize the targeting signals, as well as docking proteins on the cytosolic surface of the peroxisome. At least 23 distinct proteins, called peroxins, participate as components in the process, which is driven by ATP hydrolysis. Oligomeric proteins do not have to unfold to be imported into peroxisomes, indicating that the mechanism is distinct from that used by mitochondria and chloroplasts and at least one soluble import receptor, the peroxin Pex5, accompanies its cargo all the way into peroxisomes and, after cargo release, cycles back out

into the cytosol. These aspects of peroxisomal protein import resemble protein transport into the nucleus.

Functions:

1. Hydrogen peroxide metabolism and detoxification: Peroxisomes are so-called, because they usually contain one or more enzymes (D-amino acid oxidase and urate oxidase) that use molecular oxygen to remove hydrogen atoms from specific organic substrates (R) in an oxidative reaction that produces hydrogen peroxide (H_2O_2): $RH_2 + O_2 \longrightarrow R + H_2O_2$

This type of oxidative reaction is particularly important in liver and kidney cells, whose peroxisomes detoxify various toxic molecules that enter the blood stream. Almost half of alcohol one drinks is oxidized to acetaldehyde in this way. However, when excess H_2O_2 accumulates in the cell, catalase converts H_2O_2 to H_2O : $2H_2O_2 \longrightarrow 2H_2O + O_2$

Catalase also utilizes the H_2O_2 generated by other enzymes in the organelle to oxidize a variety of other substrates like phenols, formic acid, formaldehyde, and alcohol. This type of oxidative reaction occurs in liver and kidney cells, where the peroxisomes detoxify various toxic molecules that enter the bloodstream.

2. Photorespiration: In green leaves, there are peroxisomes that carry out a process called photorespiration which is a light-stimulated production of CO_2 that is different from the generation of CO_2 by mitochondria in the dark. In photorespiration, glycolic acid a two-carbon product of photosynthesis is released from chloroplasts and oxidized into glyoxylate and H_2O_2 by a peroxisomal enzyme called glycolic acid oxidase. Later on, glyoxylate is oxidized into CO_2 and formate:

$CH_2OH.COOH + O_2 \longrightarrow CHO - COOH + H_2O_2$

$CHO — COOH + H_2O_2 \longrightarrow HCOOH + CO_2 + H_2O$

3. Fatty acid oxidation: A major function of the oxidative reactions performed in peroxisomes is the breakdown of fatty acid molecules. In mammalian cells, β oxidation occurs in both mitochondria and peroxisomes; in yeast and plant cells, however, this essential reaction occurs exclusively in peroxisomes. Peroxisomal oxidation of fatty acids yield acetyl groups and is not linked to ATP formation. The energy released during peroxisomal oxidation is converted into heat, and the acetyl groups are transported into the cytosol, where they are used in the synthesis of cholesterol and other metabolites. In most eukaryotic cells, the peroxisome is the principal organelle in which fatty acids are oxidized, thereby generating precursors for important biosynthetic pathways. In contrast with the oxidation of fatty acids in mitochondria, which produces CO_2 and is coupled to the generation of ATP, peroxisomal oxidation of fatty acids yield acetyl groups and is not linked to ATP formation. The energy released during peroxisomal oxidation is converted into heat, and the acetyl groups are transported into the cytosol, where they are used in the synthesis of cholesterol and other metabolites.

4. Formation of plasmalogens: An essential biosynthetic function of animal peroxisomes is to catalyze the first reactions in the formation of plasmalogens, which are the most abundant class of phospholipids in myelin. Deficiency of plasmalogens causes profound abnormalities in the myelination of nerve cells, which is one reason why many peroxisomal disorders lead to neurological disease.

Plastids

Plant cells are readily distinguished from animal cells by the presence of two types of membrane-bounded compartments– vacuoles and plastids.

Types of plastids:

The term 'plastid' is derived from the Greek word "*plastikas*" (formed or moulded) and was used by A.F.W. Schimper in 1885. Schimper classified the plastids into following types according to their structure, pigments and the functions:

1. Leucoplasts

The leucoplasts (*leuco* = white; *plast* = living) are the colourless plastids which are found in embryonic and germ cells. They are also found in meristematic cells and in those regions of the plant which do not receive light. Plastids located in the cotyledons and the primordium of the stem are colourless (leucoplastes) but eventually become filled with chlorophyll and transform into chloroplasts. True leucoplasts occur in fully differentiated cells such as epidermal and internal plant tissues. True leucoplasts do not contain thylakoids and even ribosomes. They store the food materials as carbohydrates, lipids and proteins and accordingly are of following types:

(i) Amyloplasts. The amyloplasts (*amyl*=starch; *plast*=living) are those leucoplasts which synthesize and store the starch. The amyloplasts occur in those cells which store the starch. The outer membrane of the amyloplst encloses the stroma and contains one to eight starch granules. Starch granules of amyloplasts are typically composed of concentric layers of starch.

(ii) Elaioplasts. The elaioplasts store the lipids (oils) and occur in seeds of monocotyledons and dicotyledons. They also include sterol-rich sterinochloroplast.

(iii) Proteinoplasts. The proteinoplasts are the protein storing plastids which mostly occur in seeds and contain few thylakoids.

2. Chromoplasts

The chromoplasts (*chroma*=colour; *plast*=living) are the coloured plastids containing carotenoids and other pigments. They impart colour (yellow, orange and red) to certain portions of plants such as flower petals (daffodils, rose), fruits (tomatoes) and some roots (carrots). Chromoplast structure is quite diverse; they may be round, ellipsoidal, or even needle-shaped, and the carotenoids that they contain may be localized in droplets or in crystalline structures. In general, chromoplasts have a reduced chlorophyll content and are, thus, less active photosynthetically. The red colour of ripe tomatoes is the result of chromoplasts that contain the red pigment lycopene which is a member of carotenoid family. Chromoplasts of blue-green algae or cyanobacteria contain various pigments such as phycoerythrin, phycocyanin, chlorophyll a and carotenoids.

Chromoplasts are of following two types:

(i) Phaeoplast. The phaeoplast (*phaeo*=dark or brown; *plast*=living) contains the pigment fucoxanthin which absorbs the light. The phaeoplasts occur in the diatoms, dinoflagellates and brown algae.

(ii) Rhodoplast. The rhodoplast (*rhode*= red; *plast*=living) contains the pigment phaeoerythrin which absorbs the light. The rhodoplasts occur in the red algae.

3. Chloroplasts

The chloroplast (*chlor*=green; *plast*=living) is most widely occurring chromoplast of the plants. It occurs mostly in the green algae and higher plants. The chloroplast contains the pigment chlorophyll a and chlorophyll b and DNA and RNA.

Chloroplasts

Chloroplasts were described as early as seventeenth century by Nehemiah Grew and Antonie van Leeuwenhoek.

Distribution:

The chloroplasts remain distributed homogeneously in the cytoplasm of plant cells. But in certain

cells, the chloroplasts become concentrated around the nucleus or just beneath the plasma membrane. The chloroplasts have a definite orientation in the cell cytoplasm. Chloroplasts are motile organelles, and show passive and active movements.

Morphology:

Shape: Higher plant chloroplasts are generally biconvex or plano-convex. However, in different plant cells, chloroplasts may have various shapes, *viz*., filamentous, saucer-shaped, spheroid, ovoid, discoid or club-shaped. They are vesicular and have a colourless centre.

Size: The size of the chloroplasts varies from species to species. They generally measure 2–3μm in thickness and 5–10μm in diameter (*Chlamydomonas*). The chloroplasts of polyploid plant cells are comparatively larger than those of the diploid counterparts. Generally, chloroplasts of plants grown in the shade are larger and contain more chlorophyll than those of plants grown in sunlight.

Ultrastructure:

Chloroplast comprises of three main components:

1. Envelope

The entire chloroplast is bounded by a double unit membrane. Across this double membrane envelope occurs exchange of molecules between chloroplast and cytosol. Isolated membranes of envelope of chloroplast lack chlorophyll pigment and cytochromes but have a yellow colour due to the presence of small amounts of carotenoids. They contain only 1 to 2 per cent of the total protein of the chloroplast.

2. Stroma

The matrix or stroma fills most of the volume of the chloroplasts and is a kind of gel-fluid phase

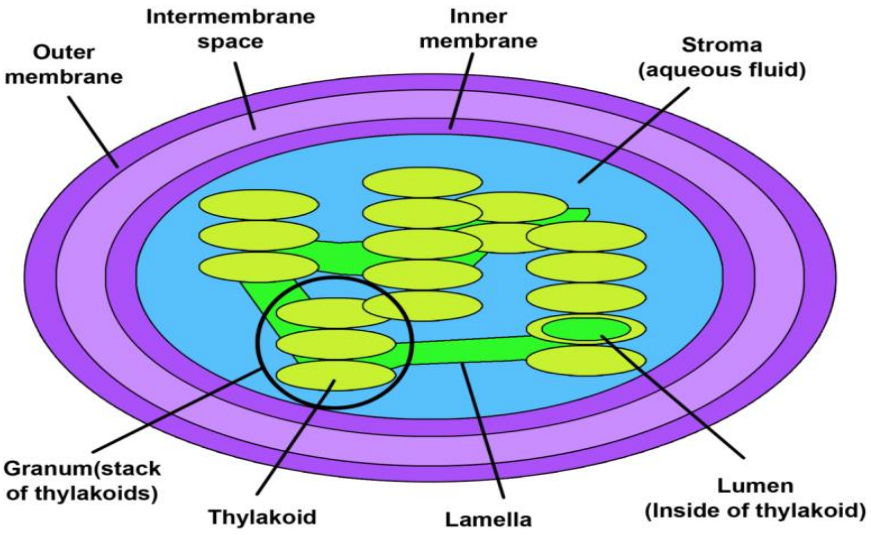
that surrounds the thylakoids (grana). It contains about 50 per cent of the proteins of the chloroplast, most of which are soluble type. The stroma also contains ribosomes and DNA molecules both of which are involved in the synthesis of some of the structural proteins of the chloroplast. The stroma is the place where CO2 fixation occurs and where the synthesis of sugars, starch, fatty acids and some proteins takes place.

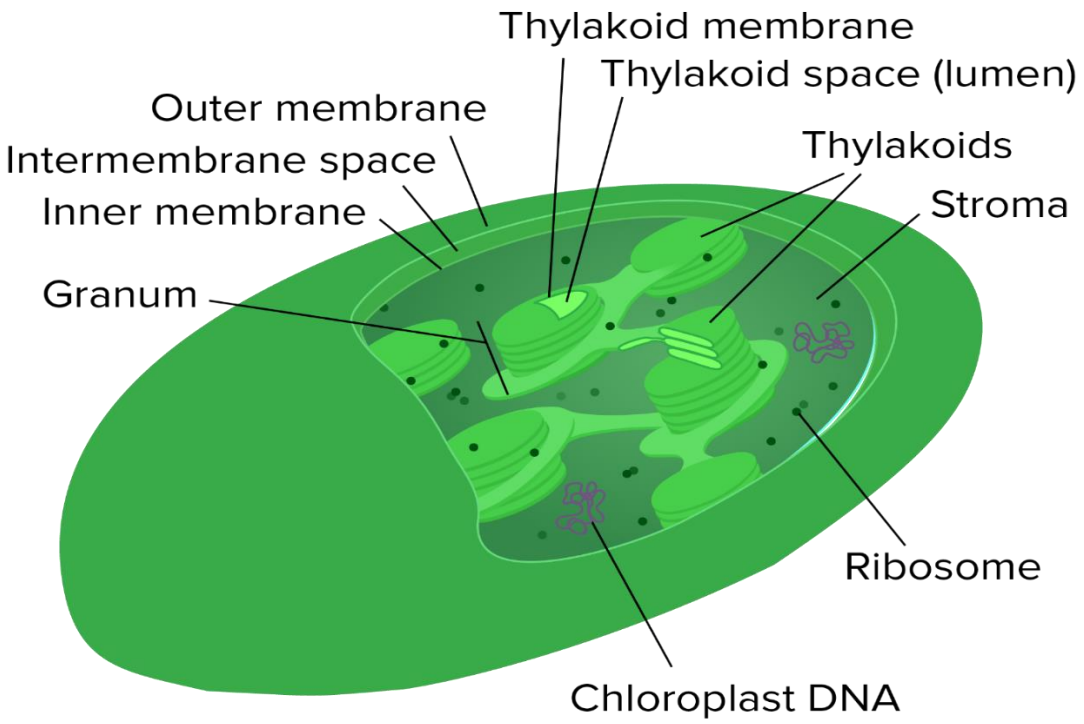
3. Thylakoids

The thylakoids (thylakoid = sac-like) consists of flattened and closed vesicles arranged as a membranous network. The outer surface of the thylakoid is in contact with the stroma, and its inner surface encloses an intrathylakoid space. Thylakoids get stacked forming grana. There may be 40 to 80 grana in the matrix of a chloroplast. The number of thylakoids per granum

may vary from 1 to 50 or more. For example, there may be single thylakoid (red alga), paired thylakoids (Chrysophyta), triple thylakoids and multiple thylakoids (green algae and higher plants).

Like the mitochondria, the chloroplasts have their own DNA, RNAs and protein synthetic machinery and are semiautonomous in nature. Chloroplasts are the largest and the most prominent organelles in the cells of plants and green algae. Chloroplasts and mitochondria have other features in common: both often migrate from place to place within cells, and they contain their own DNA, which encodes some of the key organellar proteins. Though most of the proteins in each organelle are encoded by nuclear DNA and are synthesized in the cytosol, the proteins encoded by mitochondrial or chloroplast DNA is synthesized on ribosomes within the organelles.



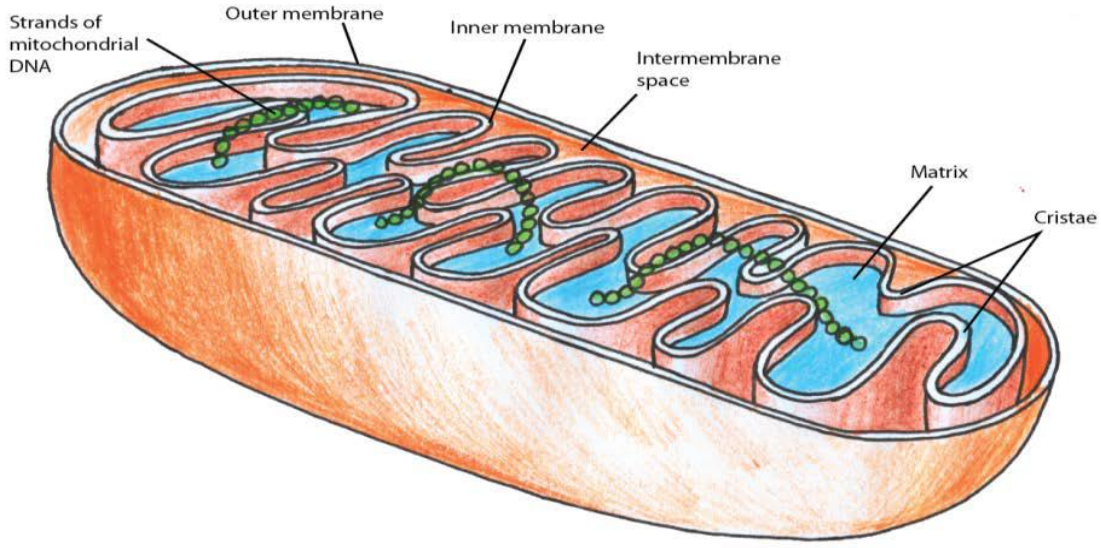


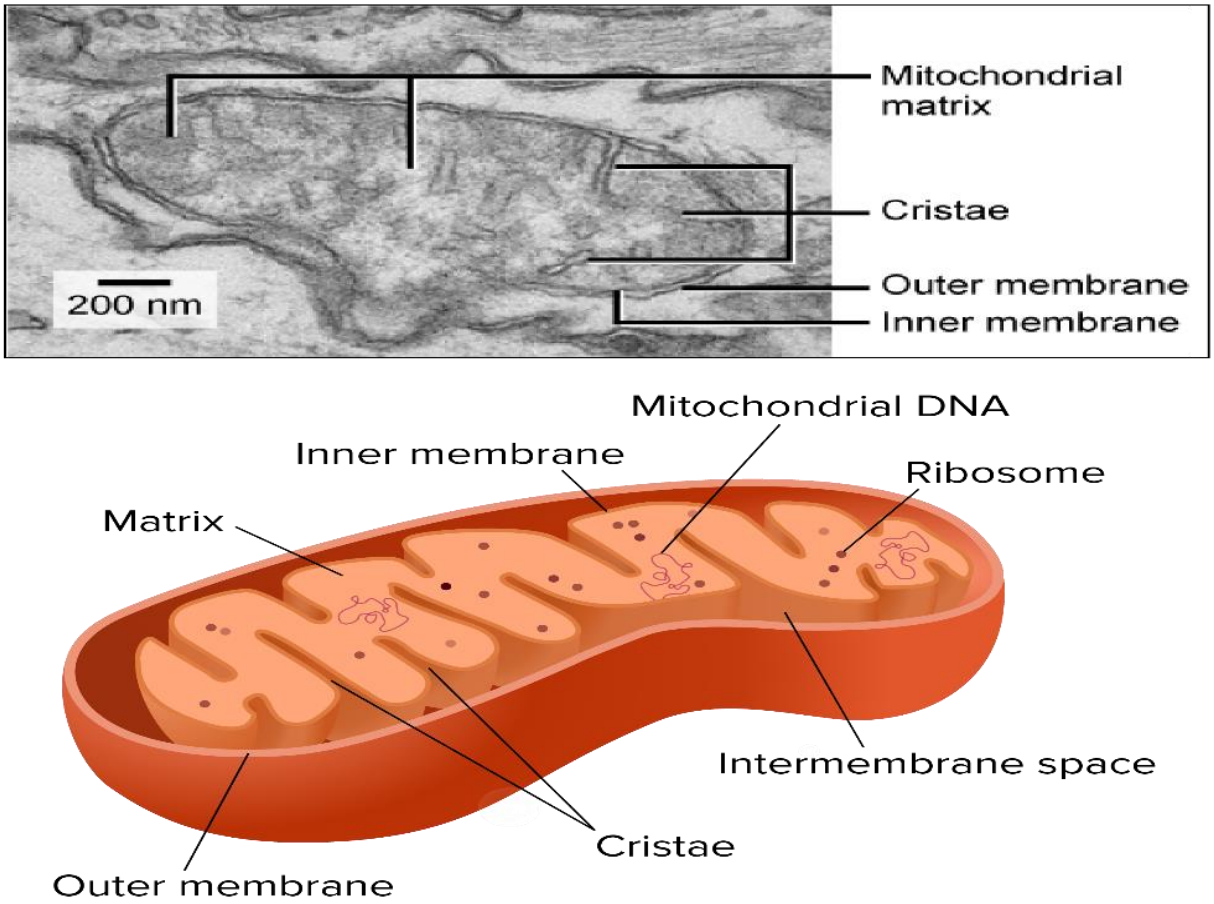
Chloroplasts have a highly permeable outer membrane; a much less permeable inner membrane, in which membrane transport proteins are embedded; and a narrow intermembrane space in between. Together, these membranes form the chloroplast envelope. The inner membrane surrounds a large space called the stroma, and contains many metabolic enzymes.

Mitochondria

Structure and Function

The mitochondria were first observed by Kolliker in 1850 as granular structures in the striated muscles. Mitochondria are called the 'powerhouse of the cell'. They are intracellular organelles found in almost all eukaryotic cells having bilayered membranes. Most eukaryotic cells contain many mitochondria, which occupy up to 25 percent of the volume of the cytoplasm. These crucial organelles, the main sites of ATP production during aerobic metabolism, are generally exceeded in size only by the nucleus, vacuoles, and chloroplasts. They are responsible for aerobic metabolism through oxidative phosphorylation, which leads to energy production in the form of adenosine triphosphate (ATP). Mitochondria contain a number of enzymes and proteins that help in processing carbohydrates and fats obtained from food we eat to release energy. Each human cell contains on average hundreds to thousands of mitochondria. The exception is mature red blood cells, which rely exclusively on anaerobic metabolism and contain no mitochondria. Figure 3 gives the schematic representation of a typical mitochondria.





Electron micrograph of a mitochondrion, showing matrix, cristae, outer membrane, and inner membrane.

Morphology:

Number: The number of mitochondria in a cell depends on the type and functional state of the cell. It varies from cell to cell and from species to species. Certain cells contain exceptionally large number of the mitochondria, for example the *Amoeba, Chaos chaos* contain 50,000; eggs of sea urchin contain 140,000 to 150,000 and oocytes of amphibians contain 300,000 mitochondria. Liver cells of rat contain only 500 to 1600 mitochondria. The cells of green plants contain less number of mitochondria in comparison to animal cells. Some algal cells may contain only one mitochondrion.

Shape: The mitochondria may be filamentous or granular in shape and may change from one form to another depending upon the physiological conditions of the cells. Thus, they may be of club, racket, vesicular, ring or round-shape. Mitochondria are granular in primary spermatocyte or rat, or club-shaped in liver cells. Time-lapse picturisation of living cells shows that mitochondria are remarkably mobile and plastic organelles, constantly changing their shape. They sometimes fuse with one another and then separate again. For example, in certain euglenoid cells, the mitochondria fuse into a reticulate structure during the day and dissociate during darkness. Similar changes have been reported in yeast species, apparently in response to culture conditions.

Size: Normally mitochondria vary in size from 0.5 μm to 2.0 μm and, therefore, are not distinctly visible under the light microscope. Sometimes their length may reach up to 7 μm.

Structure: Each mitochondrion is bound by two highly specialized membranes that play a crucial role in its activities. Each of the mitochondrial membrane is 6 nm in thickness and fluidmosaic in ultrastructure. The membranes are made up of phospholipids and proteins. The space in between the two membranes is called the inter-membrane space which has the same composition as the cytoplasm of the cell. Inner and the outer membrane is separated by a 6–8 nm wide space.

Outer Membrane

The two membranes that bound a mitochondrion differ in composition and function. The outer membrane, composed of about half lipid and half protein, contains porins that render the membrane permeable to molecules having molecular weights as high as 10,000 dalton. In this respect, the outer membrane of mitochondria is similar to the outer membrane of gram-negative bacteria. The outer membrane is smooth unlike the inner membrane and has almost the same amount of phospholipids as proteins. It has a large number of special proteins called porins that allow molecules of 5000 daltons or less in weight to pass through it. It is completely permeable to nutrient molecules, ions, ATP and ADP molecules.

Inner Membrane

The inner membrane is much less permeable, than the outer membrane. It has about 20 percent lipid and 80 percent protein. The surface area of the inner membrane is greatly increased by a large number of infoldings, or finger like projections called cristae, that protrude into the matrix, or central space, increasing the surface area for the complexes. It contains the complexes of the electron transport chain and the ATP synthetase complex, they also serve to separate the matrix from the space that will contain the hydrogen ions, allowing the gradient needed to drive the pump. It is permeable only to oxygen, carbon dioxide and water and is made up of a large number of proteins that play an important role in producing ATP, and also helps in regulating transfer of metabolites across the membrane. In general, the cristae of plant mitochondria are tubular, while those of animal mitochondria are lamellar or plate-like. Some mitochondria, particularly those from heart, kidney and skeletal muscles have more extensive cristae arrangements than liver mitochondria. In comparison to these, other mitochondria (from fibroblasts, nerve axons and most plant tissues) have relatively few cristae.

Attached to matrix face of inner mitochondrial membrane are repeated units of stalked particles, called elementary particles, inner membrane subunits or oxysomes. They are also identified as F1 particles or F0-F1 particles and are meant for ATP synthesis (phosphorylation) and also for ATP oxidation (acting as ATP synthetase and ATPase). F0-F1 particles are regularly spaced at intervals of 10 nm on the inner surface of inner mitochondrial membrane. According to some estimates, there are 104 to 105 elementary particles per mitochondrion. When the mitochondrial cristae are disrupted by sonic vibrations or by detergent action, they produce submitochondrial vesicles of inverted orientation. In these vesicles, F0-F1 particles are seen attached on their outer surface. These submitochondrial vesicles are able to per- form respiratory chain phosphorylation. However, in the absence of F0-F1 particles, these vesicles lose their capacity of phosphorylation as shown by resolution (removal by urea or trypsin treatment) and reconstitution of these particles.

Matrix

The matrix is a complex mixture of enzymes that are important for the synthesis of ATP molecules, special mitochondrial ribosomes, tRNAs and the mitochondrial DNA. Besides these, it has oxygen, carbon dioxide and other recyclable intermediates.

Chemical composition

Mitochondria are found to contain 65 to 70 per cent proteins, 25 to 30 per cent lipids, 0.5 per cent RNA and small amount of the DNA. The lipid contents of the mitochondria is around 90 per cent phospholipids (lecithin and cephalin), 5 per cent or less cholesterol and 5 per cent free fatty acids and triglycerides. The inner membrane is rich in one type of phospholipid, called cardiolipin which makes this membrane impermeable to a variety of ions and small molecules (Na+, K+, Cl-, NAD+,AMP, GTP, CoA and so on). The outer mitochondrial membrane has typical ratio of 50 per cent proteins and 50 per cent phospholipids of 'unit membrane'. However, it contains more unsaturated fatty acids and less cholesterol. It has been estimated that in the mitochondria of liver 67 per cent of the total mitochondrial protein is located in the matrix, 21 per cent is located in the inner membrane, 6 per cent is situated in the outer membrane and 6 per cent is found in the outer chamber. Each of these four mitochondrial regions contains a special set of proteins that mediate distinct functions. Besides Porin, enzymes of outer membrane consists of, other proteins involved in mitochondrial lipid synthesis and those enzymes that convert lipid substrates into forms that are subsequently metabolized in the matrix. Certain important enzymes of this membrane are monoamine oxidase, rotenone-insensitive NADH-cytochrome-C-reductase, kynurenine hydroxyalase, and fatty acid CoA ligase. Enzymes of intermembrane space contains several enzymes that use the ATP molecules passing out of the matrix to phosphorylate other nucleotides. The main enzymes of this part are adenylate kinase and nucleoside diphosphokinase. Enzymes of inner membrane contains proteins with three types of functions: 1. Those that carry out the oxidation reactions of the respiratory chain; 2. an enzyme complex, called ATP synthetase that makes ATP in matrix ; and 3. specific transport proteins The significant enzymes of inner membrane are enzymes of electron transport pathways, namely nicotinamide adenine dinucleotide (NAD), flavin adenine dinucleotide (FAD), diphosphopyridine nucleotide (DPN) dehydrogenase, four cytochromes (Cyt. b, Cyt. c, Cyt.c1, Cyt. a and Cyt. a3), ubiquinone or coenzyme Q10, non-heme copper and iron, ATP synthetase, succinate dehydrogenase; β-hydroxybutyrate dehydrogenase; carnitive fatty acid acyl transferase. Enzymes of mitochondrial matrix contains various enzymes, including those required for the oxidation of pyruvate and fatty acids and for the citric acid cycle. The matrix also contains several identical copies of the mitochondrial DNA, special 55S mitochondrial ribosomes, tRNAs and various enzymes required for the expression of mitochondrial genes. Thus, the mitochondrial matrix contains malate dehydrogenase, isocitrate dehydrogenase, fumarase, aconitase, citrate synthetase, ⟨-keto acid dehydrogenase, β-oxidation enzymes.

Function of mitochondria

1. The most important function of the mitochondria is to produce energy. The food that we eat is broken into simpler molecules like carbohydrates, fats, etc., in our bodies. These are sent to the mitochondrion where they are further processed to produce charged molecules that combine

with oxygen and produce ATP molecules. This entire process is known as oxidative phosphorylation.

2. It is important to maintain proper concentration of calcium ions within the various compartments of the cell. Mitochondria help the cells to achieve this goal by serving as storage tanks of calcium ions.

3. Mitochondria help in the building of certain parts of the blood, and hormones like testosterone and estrogen.

4. Mitochondria in the liver cells have enzymes that detoxify ammonia.

Ribosomes

Ribosomes are the protein synthesis units of a cell described by G.E. Palade in 1952. They are complex of ribosomal RNA and various proteins. Their presence in both free and endoplasmis reticulum membrane attached form (rough endoplasmic reticulum) was confirmed by Palade and Siekevitz by the electron microscopy. We will have discussion about endoplasmic reticulum in this lecture after discussion about ribosome. Ribosomes are small, dense, rounded and granular particles of the ribonucleoprotein. As mentioned, they occur either freely in the matrix of mitochondria, chloroplast and cytoplasm or remain attached with the membranes of the endoplasmic reticulum. They occur in most prokaryotic and eukaryotic cells and provide a scaffold for the ordered interaction of all the molecules involved in protein synthesis. They are the most abundant RNA-protein complex in the cell, which directs elongation of a polypeptide at a rate of three to five amino acids added per second. Small proteins of 100–200 amino acids are therefore made in a minute or less. On the other hand, it takes 2–3 hours to make the largest known protein, titin, which is found in muscle and contains about 30,000 amino acid residues.

Occurrence and distribution:

The ribosomes occur in both prokaryotic and eukaryotic cells. In prokaryotic cells the ribosomes often occur freely in the cytoplasm or sometimes as polyribosome. In eukaryotic cells the ribosomes either occur freely in the cytoplasm or remain attached to the outer surface of the membrane of endoplasmic reticulum. The yeast cells, reticulocytes or lymphocytes, meristamatic plant tissues, embryonic nerve cells and cancerous cells contain large number of ribosomes which often occur freely in the cytoplasmic matrix. Cells like the erythroblasts, developing muscle cells, skin and hair which synthesize specific proteins for the intracellular utilization and storage contain also contain large number of free ribosomes. In cells with active protein synthesis, the ribosomes remain attached with the membranes of the endoplasmic reticulum.

Types of ribosomes:

Ribosomes are classified into two types based on their sedimentation coefficient, 70S and 80S. S stands for Svedberg unit and related to sedimentation rate (sedimentation depends on mass and size). Thus, the value before S indicates size of ribosome.

70S Ribosomes: Prokaryotes have 70S ribosemes. The 70S ribosomes are comparatively smaller in size and have sedimentation coefficient 70S with molecular weight 2.7× 106 daltons. Electron microscopy measures the dimension of the 70S ribosomes as170 ×170 × 200 Ao. They occur in the prokaryotic cells of the blue green algae and bacteria and also in mitochondria and chloroplasts of eukaryotic cells.

80S Ribosomes: Eukaryotes have 80S ribosomes. The 80S ribosomes have sedimentation coefficient of 80S and molecular weight 40 × 106 daltons. The 80S ribosomes occur in eukaryotic cells of the plants and animals. The ribosomes of mitochondria and chloroplasts are always smaller than 80S cytoplasmic ribosomes and are comparable to prokaryotic ribosomes in both size and sensitivity to antibiotics. However their sedimentation values vary in different phyla, 77S in mitochondria of fungi, 60S in mitochondria of mammals and 60S in mitochondria of animals.

Number of ribosomes:

An *E. coli* cell contains 10,000 ribosomes, forming 25 per cent of the total mass of the bacterial cell. Whereas, mammalian cultured cells contain 10 million ribosomes per cell.

Chemical composition:

The ribosomes are chemically composed of RNA and proteins as their major constituents; both occurring approximately in equal proportions in smaller as well as larger subunit. The 70S ribosomes contain more RNA (60 to 40%) than the proteins (36 to 37%). The ribosomes of *E. coli* contain 63% rRNA and 37% protein. While the 80S ribosomes contain less RNA (40 to 44%) than the proteins (60 to 56%), yeast ribosomes have 40 to 44% RNA and 60 to 56% proteins; ribosomes of pea seedling contain 40% RNA and 60% proteins. There is no lipid content in ribosomes.

Structure

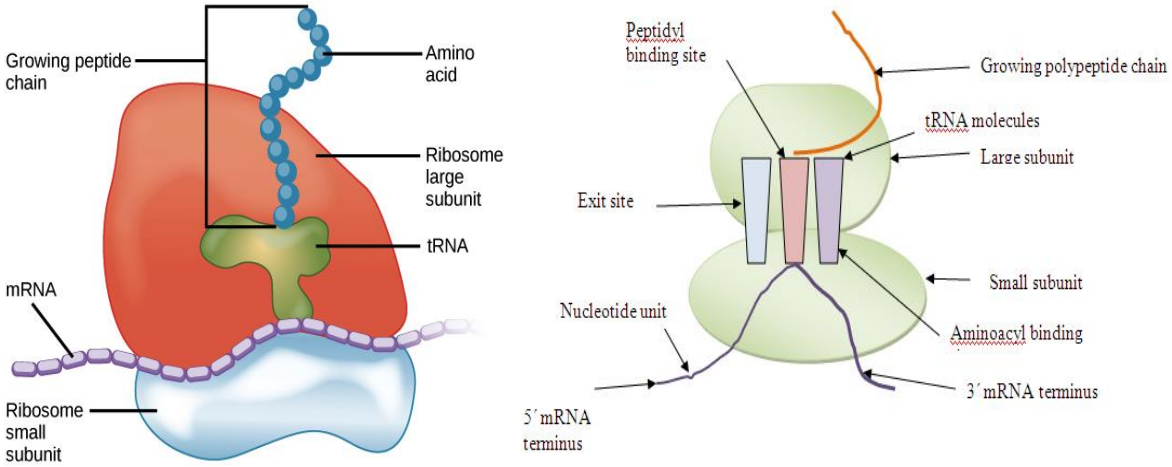
The ribosomes are oblate spheroid structures of 150 to 250Ao in diameter. Each ribosome is porous, hydrated and composed of two subunits. One ribosomal subunit is large in size and has a domelike shape, while the other ribosomal subunit is smaller in size, occurring above the larger subunit and forming a cap-like structure. The small ribosomal subunit contains a single rRNA molecule, referred to as small *rRNA.* The large subunit contains a molecule of large *rRNA* and one molecule of 5S rRNA, plus an additional molecule of 5.8S rRNA in vertebrates. The lengths of the rRNA molecules, the quantity of proteins in each subunit, and consequently the sizes of the subunits differ in bacterial and eukaryotic cells. The assembled ribosome is 70S in bacteria and 80S in vertebrates. There are great structural and functional similarities between ribosomes from all species which is another reflection of the common evolutionary origin of the most basic constituents of living cells.

The 70S ribosome consists of two subunits, 50S and 30S. The 50S ribosomal subunit is larger in size and has the size of 160 Ao to 180 Ao. The 30S ribosomal subunit is smaller in size and occurs above the 50S subunit like a cap. The 80S ribosome also consists of two subunits, 60S and 40S. The 60S ribosomal subunit is dome-shaped and larger in size. In the ribosomes which remain attached with the membranes of endoplasmic reticulum and nucleus, the 60S subunit remains attached with the membranes. The 40S ribosomal subunit is smaller in size and occurs above the 60s subunit forming a cap-like structure. Both the subunits remain separated by a narrow cleft. The two ribosomal subunits remain united with each other due to high concentration of the Mg++ (.001M) ions. When the concentration of Mg++ions reduces in the matrix, both ribosomal subunits get separated. Actually in bacterial cells the two subunits are found to occur freely in the cytoplasm and they unite only during the process of protein synthesis. At high concentration of Mg++ ions in the

matrix, the two ribosomes (monosomes) become associated with each other and known as the

dimer. Further, during protein synthesis many ribosomes are aggregated due to common messenger RNA and form the polyribosomes or polysomes.

The actual three-dimensional structures of bacterial rRNAs from *Thermus thermopolis* recently have been determined by x-ray crystallography of the 70S ribosome. The multiple, much smaller ribosomal proteins for the most part are associated with the surface of the rRNAs. During translation, a ribosome moves along an mRNA chain, interacting with various protein factors and tRNAs and very likely undergoing large conformational changes. Despite the complexity of the ribosome, great progress has been made in determining the overall structure of bacterial ribosomes and in identifying various reactive sites. X-ray crystallographic studies on the *T. thermophilus* 70S ribosome, for instance, not only have revealed the dimensions and overall shape of the ribosomal subunits but also have localized the positions of tRNAs bound to the ribosome during elongation of a growing protein chain. In addition, powerful chemical techniques such as footprinting, have been used to identify specific nucleotide sequences in rRNAs that bind to protein or another RNA.

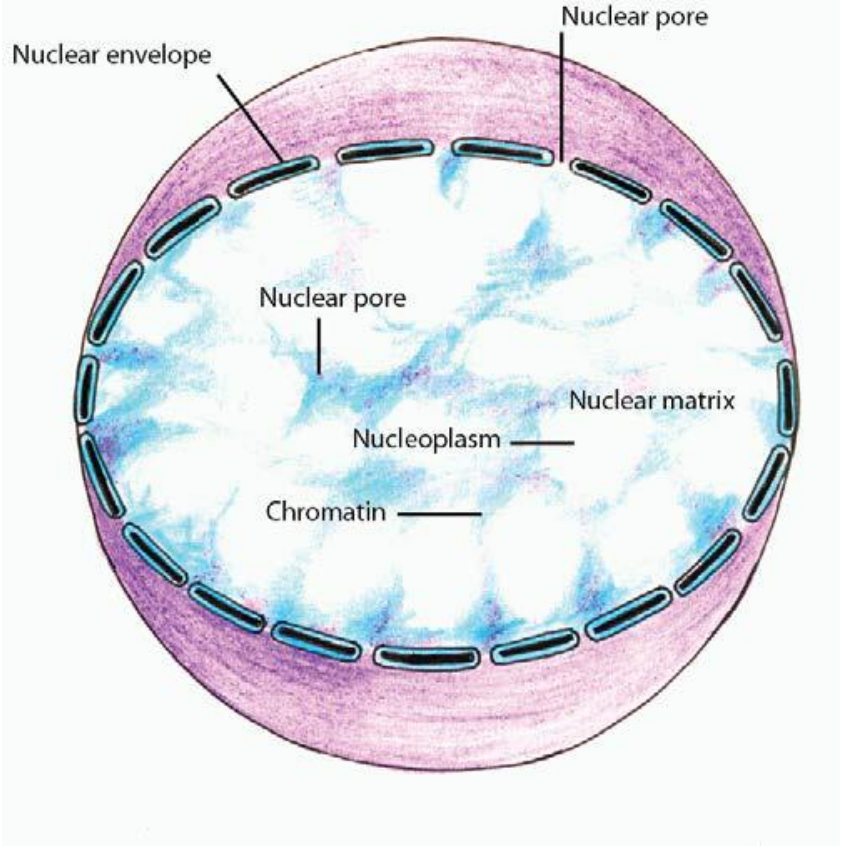


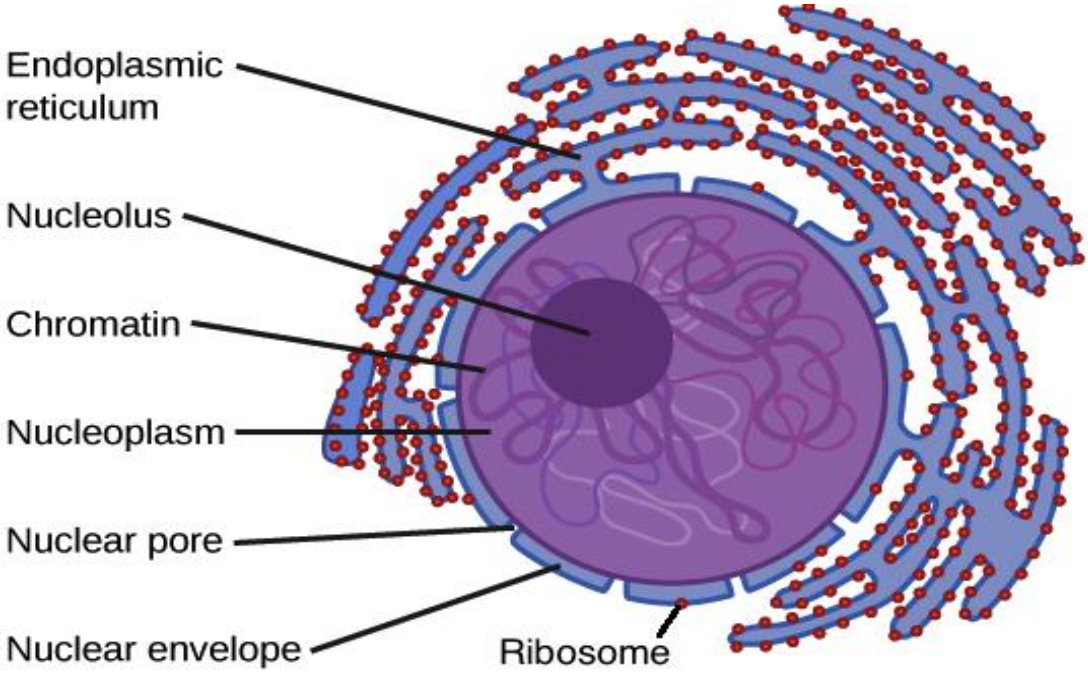
The detailed structure of a ribosome involved in protein synthesis.

Nucleus

Nucleus means kernel and was the first organelle to be discovered. It was discovered and named by Robert Brown in 1833 in the plant cells and is recognized as a constant feature of all animal and plant cells. Certain eukaryotic cells such as the mature sieve tubes of higher plants and mammalian erythrocytes contain no nucleus. It is the largest cellular organelle in eukaryotes. Prokaryotic cells lack nucleus and is complemented by nucleoid. In mammalian cells, the average diameter of the nucleus is approximately 6 micrometres (μm), occupying about 10% of the total cell volume. The contents of the nucleus are DNA genome, RNA synthetic apparatus, and a fibrous matrix. It is surrounded by two membranes, each one a phospholipid bilayer containing many different types of proteins. The inner nuclear membrane defines the nucleus itself. In most cells, the outer nuclear membrane is continuous with the rough endoplasmic reticulum, and the space between the inner and outer nuclear membranes is continuous with the lumen of the rough endoplasmic reticulum. The two nuclear membranes appear to fuse at nuclear pores, the ring like complexes composed of specific membrane proteins through which material moves between the nucleus and the cytosol. It contains cell's

genetic material, organized as multiple long linear DNA molecules in complex with histones, to form chromosomes. The genes within these chromosomes are the cell's nuclear genome. The function is to maintain the integrity of the genes that controls the activities of the cell by regulating gene expression.





In a growing or differentiating cell, the nucleus is metabolically active, replicating DNA and synthesizing rRNA, tRNA, and mRNA. Within the nucleus mRNA binds to specific proteins, forming ribonucleoprotein particles. Most of the cell's ribosomal RNA is synthesized in the nucleolus, a subcompartment of the nucleus that is not bounded by a phospholipid membrane. Some ribosomal proteins are added to ribosomal RNAs within the nucleolus as well. The finished or partly finished ribosomal subunits, as well as tRNAs and mRNA-containing particles, pass through a nuclear pore into the cytosol for use in protein synthesis. In a nucleus that is not dividing, the chromosomes are dispersed and not dense enough to be observed in the light microscope. Only during cell division are individual chromosomes visible by light microscopy. In the electron microscope, the nonnucleolar regions of the nucleus, called the nucleoplasm, can be seen to have dark and light staining areas. The dark areas, which are often closely associated with the nuclear membrane, contain condensed concentrated DNA, called heterochromatin. Fibrous proteins called lamins form a two-dimensional network along the inner surface of the inner membrane, giving it shape and apparently binding DNA to it. The breakdown of this network occurs early in cell division.

Cell Nucleus: Ultrastructure

The structure of a cell nucleus consists of a nuclear membrane (nuclear envelope), nucleoplasm, nucleolus, and chromosomes. Nucleoplasm, also known as karyoplasm, is the matrix present inside the nucleus. Following section discusses in brief about the several parts of a cell nucleus.

a. Nuclear Membrane

It is a double-membrane structure each 5–10 nm thick . Numerous pores occur in the envelope, allowing RNA and other chemicals to pass, but not the DNA. Because the nuclear membrane is impermeable to most molecules, nuclear pores are required to allow movement of molecules across the envelope. These pores cross both of the membranes, providing a channel that allows free movement of small molecules and ions. The movement of larger molecules such as protein requires active transport regulated by carrier proteins. Figure 2 illustrates the nuclear membrane. The nuclear envelope (or perinuclear cisterna) encloses the DNA and defines the nuclear compartment of interphase and prophase nuclei.

The spherical inner nuclearmembrane contains specific proteins that act as binding sites for the supporting fibrous sheath ofintermediate filaments (IF), called nuclear lamina. Nuclear lamina has contact with the chromatin (or chromosomes) and nuclear RNAs. The inner nuclear membrane is surrounded by the outer nuclear membrane, which closely resembles the membrane of the endoplasmic reticulum, that is continuous with it. Like the membrane of the rough ER, the outer surface of outer nuclear membrane is generally studded with ribosomes engaged in protein synthesis. The proteins made on these ribosomes are transported into space between the inner and outer nuclear membrane, called perinuclear space. The perinuclear space is a 10 to 50 nm wide fluid-filled compartment which is continuous with the ER lumen and may contain fibres, crystalline deposits, lipid droplets or electrondense material. Nuclear pores and nucleocytoplasmic traffic. The nuclear envelope in all eukaryotic forms, from yeasts to humans, is perforated by nuclear pores which have the following structure and function:

Structure of nuclear pores: Nuclear pores appear circular in surface view and have a diameter between 10nm to 100 nm. Previously it was believed that a diaphragm made of amorphous to fibrillar material extends across each pore limiting free transfer of material. Such a diaphragm

called annulus has been observed in animal cells, but lack in plant cells. Recent electron microscopic studies have revealed that a nuclear pore has far more complex structure, so it is called nuclear pore complex with an estimated molecular weight of 50 to 100 million daltons. Negative staining techniques have demonstrated that pore complexes have an eight-fold or octagonal symmetry.

Nucleoplasm:

The space between the nuclear envelope and the nucleolus is filled by a transparent, semi-solid, granular and slightly acidophilic ground substance or the matrix known as the nuclear sap or nucleoplasm or karyolymph. The nuclear components such as the chromatin threads and the nucleolus remain suspended in the nucleoplasm which is composed mainly of nucleoproteins but it also contains other inorganic and organic substances, namely nucleic acids, proteins, enzymes and minerals. The most common nucleic acids of the nucleoplasm are the DNA and RNA. The nucleoplasm contains many types of complex proteins
categorized into: (i) Basic proteins. The proteins which take basic stain are known as the basic proteins. The most important basic proteins of the nucleus are nucleoprotamines and the nucleohistones. (ii) Non-histone or Acidic proteins. The acidic proteins either occur in the nucleoplasm or in the chromatin. The most abundant acidic proteins of the euchromatin (a type of chromatin) are the phosphoproteins. The nucleoplasm contains many enzymes which are necessary for the synthesis of the DNA and RNA. Most of the nuclear enzymes are composed of non-histone (acidic) proteins. The most important nuclear enzymes are the DNA polymerase, RNA polymerase, NAD synthetase, nucleoside triphosphatase, adenosine diaminase, nucleoside phosphorylase, guanase, aldolase, enolase, 3-phosphoglyceraldehyde dehydrogenase and pyruvate kinase. The nucleoplasm also contains certain cofactors and coenzymes such as ATP and acetyl CoA. The nucleoplasm has small lipid content. The nucleoplasm also contains several inorganic compounds such as phosphorus, potassium, sodium, calcium and magnesium. The chromatin comparatively contains large amount of these minerals than the nucleoplasm.

The nucleoplasm contains many thread-like, coiled and much elongated structures which take readily the basic stains such as the basic fuchsin. These thread-like structures are known as the chromatin (*chrome*=colour) substance or chromatin fibres. Chromosome will be discussed in detail in the next module.

Nucleolus:

Most cells contain in their nuclei one or more prominent spherical colloidal acidophilic bodies, called nucleoli. However, cells of bacteria and yeast lack nucleolus. The nucleolus is mainly involved in the assembly of ribosomes. After being produced in the nucleolus, ribosomes are exported to the cytoplasm where they translate mRNA. Some of the eukaryotic organisms have nucleus that contains up to four nucleoli. The nucleolus plays an indirect role in protein synthesis by producing ribosomes. Nucleolus disappears when a cell undergoes division and is reformed after the completion of cell-division. The size of the nucleolus is found to be related with the synthetic activity of the cell. Therefore, the cells with little or no synthetic activities, sperm cells, blastomeres, muscle cell, etc., are found to contain smaller or no nucleoli, while the oocytes, neurons and secretory cells which synthesize the proteins or other substances contain comparatively large-sized nucleoli. The number of the nucleoli in the nucleus depends on the species and the number of the chromosomes. The number of the nucleoli in the cells

may be one, two or four. A nucleolus is often associated with the nucleolar organizer (NO) which represents the secondary constriction of the nucleolar organizing chromosomes, and are 10 in number in human beings. Nucleolar organizer consists of the genes for 18S, 5.8S and 28S rRNAs. The genes for fourth type of r RNA, *i.e.,* 5S rRNA occur outside the nucleolar organizer. Nucleolus is not bounded by any limiting membrane; calcium ions are supposed to maintain its intact organization. Nucleolus also contains some enzymes such as acid phosphatase, nucleoside phosphorylase and NAD+ synthesizing enzymes for the synthesis of some coenzymes, nucleotides and ribosomal RNA. RNA methylase enzyme which transfers methyl groups to the nitrogen bases occurs in the nucleolus of some cells. Functionally nucleolus is the site where biogenesis of ribosomal subunits (40S and 60S) takes place. In it three types of rRNAs, namely 18S, 5.8S and 28S rRNAs, are transcribed as parts of a much longer precursor molecule (45S transcript) which undergoes processing (RNA splicing) by the help of two types of proteins such as nucleolin and U3 sn RNP (U3 is a 250 nucleotide containing RNA, sn RNP represents small nuclear ribonucleoprotein). The 5S r RNA is transcribed on the chromosome existing outside the nucleolus and the 70S types of ribosomal proteins are synthesized in the cytoplasm. All of these components of the ribosomes migrate to the nucleolus, where they are assembled into two types of ribosomal subunits which are transported back to the cytoplasm. The smaller (40S) ribosomal subunits are formed and migrate to the cytoplasm much earlier than larger (60S) ribosomal subunits; therefore, nucleolus contains many more incomplete 60S ribosomal subunits than the 40S ribosomal subunits. Such a time lag in the migration of 60S and 40S ribosomal subunits, prevents functional ribosomes from gaining access to the incompletely processed heterogeneous RNA (hn RNA; the precursor of m RNA) molecule inside the nucleus.

Functions of the nucleus

Speaking about the functions of a cell nucleus, it controls the hereditary characteristics of an organism. This organelle is also responsible for the protein synthesis, cell division, growth, and differentiation. Some important functions carried out by a cell nucleus are:

1. Storage of hereditary material, the genes in the form of long and thin DNA (deoxyribonucleic acid) strands, referred to as chromatins.
2. Storage of proteins and RNA (ribonucleic acid) in the nucleolus.
3. Nucleus is a site for transcription in which messenger RNA (mRNA) are produced for the protein synthesis.
4. Exchange of hereditary molecules (DNA and RNA) between the nucleus and rest of the cell.
5. During the cell division, chromatins are arranged into chromosomes in the nucleus.
6. Production of ribosomes (protein factories) in the nucleolus.
7. Selective transportation of regulatory factors and energy molecules through nuclear pores.

As the nucleus regulates the integrity of genes and gene expression, it is also referred to as the control center of a cell. Overall, the cell nucleus stores all the chromosomal DNA of an organism.

Left: image of a chromosome, showing how it is made up of DNA wound around histones and then arranged in loops and other higher-order structures. Right: false-coloured and rearranged micrograph of chromosomes.

Chromosomes – Introduction, Structure & Types

Introduction

When a cell divides, one of its main jobs is to make sure that each of the two new cells gets a full, perfect copy of genetic material. Mistakes during copying, or unequal division of the genetic material between cells, can lead to cells that are unhealthy or dysfunctional (and may lead to diseases such as cancer).

But what exactly is this genetic material, and how does it behave over the course of a cell division?

DNA and genomes

DNA (**deoxyribonucleic acid**) is the genetic material of living organisms. In humans, DNA is found in almost all the cells of the body and provides the instructions they need to grow, function, and respond to their environment.

When a cell in the body divides, it will pass on a copy of its DNA to each of its daughter cells. DNA is also passed on at the level of organisms, with the DNA in sperm and egg cells combining to form a new organism that has genetic material from both its parents.

Physically speaking, DNA is a long string of paired chemical units (nucleotides) that come in four different types, abbreviated A, T, C, and G, and it carries information organized into units called **genes**. Genes typically provide instructions for making proteins, which give cells and organisms their functional characteristics.

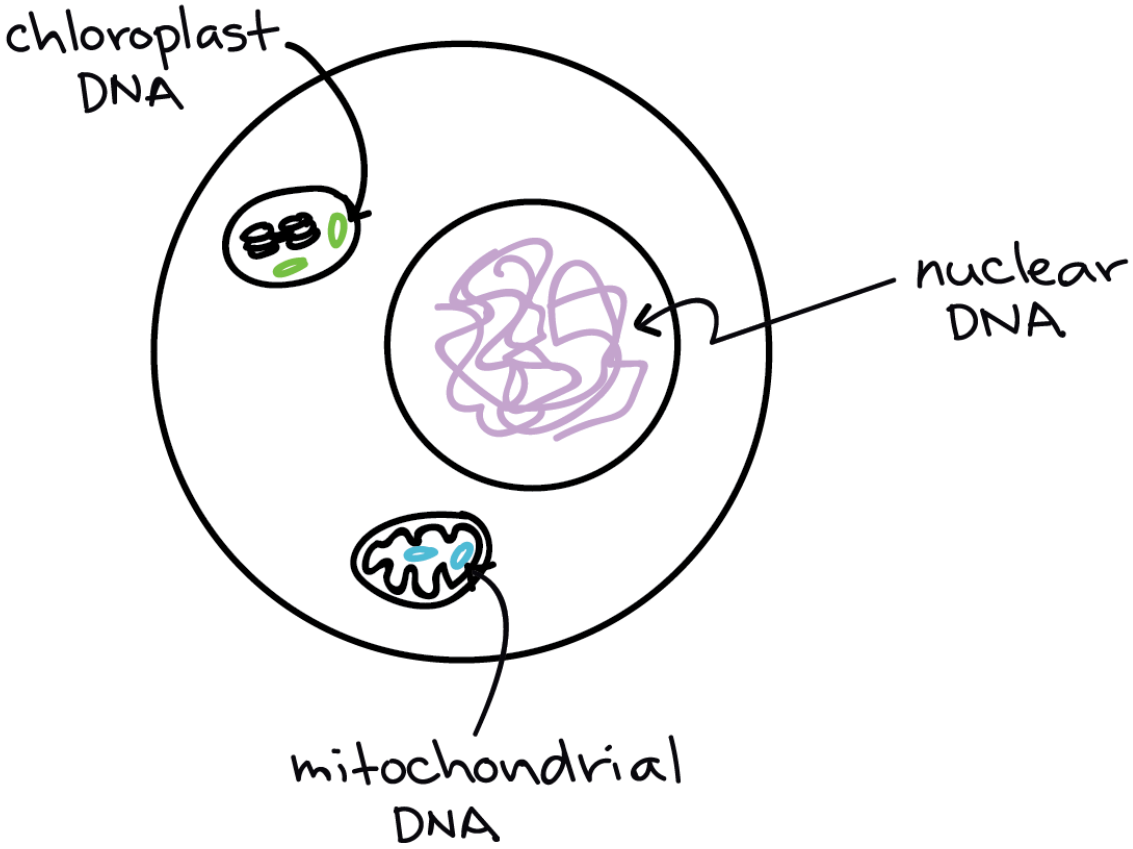


Image of a eukaryotic cell, showing the nuclear DNA (in the nucleus), the mitochondrial DNA (in the mitochondrial matrix), and the chloroplast DNA (in the stroma of the chloroplast).

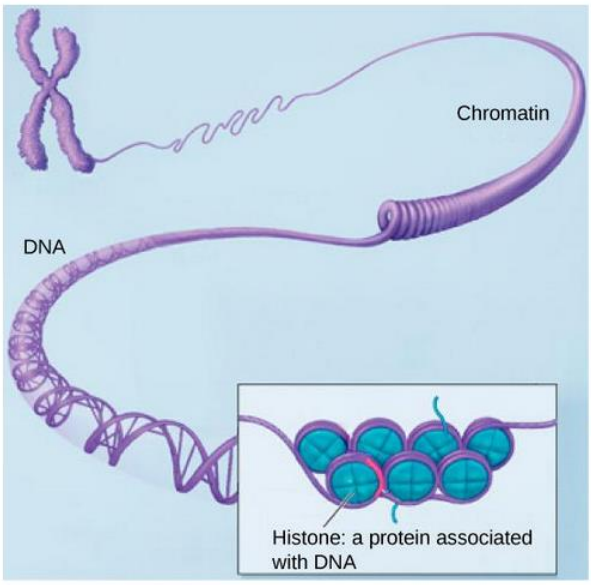
In eukaryotes such as plants and animals, the majority of DNA is found in the nucleus and is called **nuclear DNA**. Mitochondria, organelles that harvest energy for the cell, contain their own **mitochondrial DNA**, and chloroplasts, organelles that carry out photosynthesis in plant cells, also have **chloroplast DNA**. The amounts of DNA found in mitochondria and chloroplasts are much smaller than the amount found in the nucleus. In bacteria, most of the DNA is found in a central region of the cell called the **nucleoid**, which functions similarly to a nucleus but is not surrounded by a membrane.

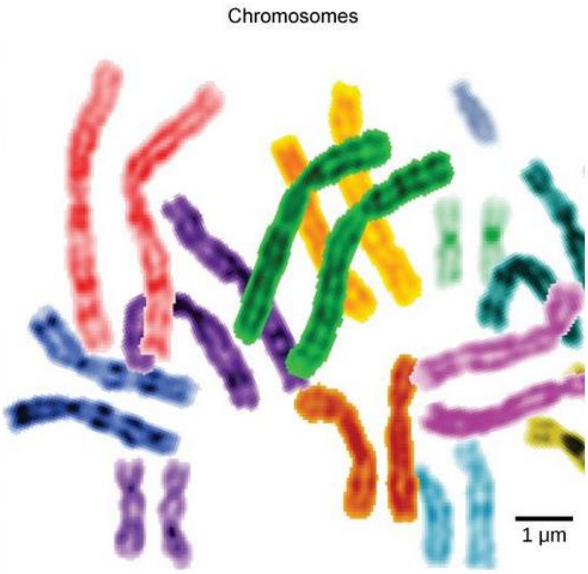
A cell's set of DNA is called its **genome**. Since all of the cells in an organism (with a few exceptions) contain the same DNA, you can also say that an organism has its own genome, and since the members of a species typically have similar genomes, you can also describe the genome of a species. In general, when people refer to the human genome, or any other eukaryotic genome, they mean the set of DNA found in the nucleus. Mitochondria and chloroplasts are considered to have their own separate genomes.

Chromatin

In a cell, DNA does not usually exist by itself, but instead associates with specialized proteins that organize it and give it structure. In eukaryotes, these proteins include the **histones**, a group

of basic (positively charged) proteins that form "bobbins" around which negatively charged DNA can wrap. In addition to organizing DNA and making it more compact, histones play an important role in determining which genes are active. The complex of DNA plus histones and other structural proteins is called **chromatin**.





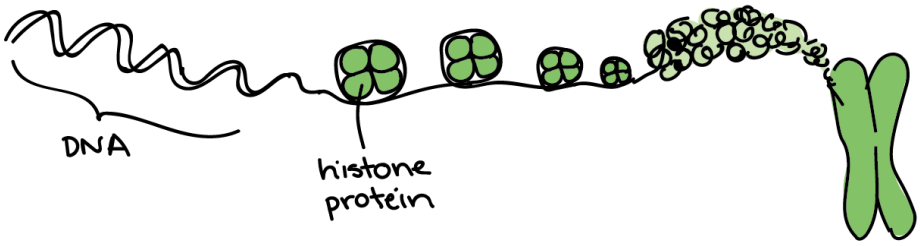


Image of a long, double-stranded DNA polymer, which wraps around clusters of histone proteins. The DNA wrapped around histones is further organized into higher-order structures that give a chromosome its shape.

For most of the life of the cell, chromatin is **decondensed**, meaning that it exists in long, thin strings that look like squiggles under the microscope. In this state, the DNA can be accessed relatively easily by cellular machinery (such as proteins that read and copy DNA), which is important in allowing the cell to grow and function.

Decondensed may seem like an odd term for this state – why not just call it "stringy"? – but makes more sense when you learn that chromatin can also **condense**. Condensation takes place when the cell is about to divide. When chromatin condenses, you can see that eukaryotic DNA is not just one long string. Instead, it's broken up into separate, linear pieces called **chromosomes**. Bacteria also have chromosomes, but their chromosomes are typically circular.

Chromosomes

Each species has its own characteristic number of chromosomes. Humans, for instance, have 46 chromosomes in a typical body cell (somatic cell), while dogs have 78^11start superscript, 1, end superscript. Like many species of animals and plants, humans are **diploid** (**2*n***), meaning that most of their chromosomes come in matched sets known as **homologous pairs**. The 46 chromosomes of a human cell are organized into 23 pairs, and the two members of each pair are said to be **homologues** of one another (with the slight exception of the X and Y chromosomes; see below).

Human sperm and eggs, which have only one homologous chromosome from each pair, are said to be **haploid** (**1*n***). When a sperm and egg fuse, their genetic material combines to form one complete, diploid set of chromosomes. So, for each homologous pair of chromosomes in your genome, one of the homologues comes from your mom and the other from your dad.

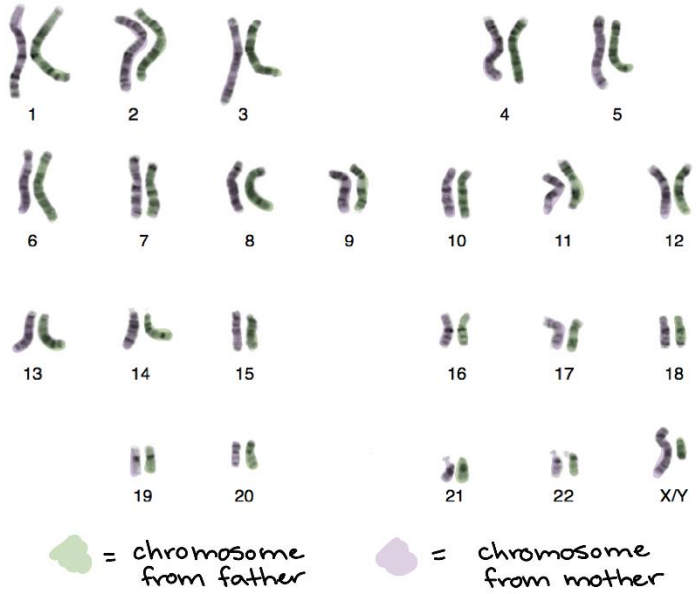


Image of the karyotype of a human male, with chromosomes from the mother and father false-colored purple and green, respectively.

Image modified from "Karyotype," by the National Institutes of Health (public domain).

The two chromosomes in a homologous pair are very similar to one another and have the same size and shape. Most importantly, they carry the same type of genetic information: that is, they have the same genes in the same locations. However, they don't necessarily have the same versions of genes. That's because you may have inherited two different gene versions from your mom and your dad.

As a real example, let's consider a gene on chromosome 9 that determines blood type (A, B, AB, or O)^22start superscript, 2, end superscript. It's possible for a person to have two identical copies of this gene, one on each homologous chromosome—for example, you may have a double dose of the gene version for type A. On the other hand, you may have two different gene versions on your two homologous chromosomes, such as one for type A and one for type B (giving AB blood).

The **sex chromosomes**, X and Y, determine a person's biological sex: XX specifies female and XY specifies male. These chromosomes are not true homologues and are an exception to the rule of the same genes in the same places. Aside from small regions of similarity needed during meiosis, or sex cell production, the X and Y chromosomes are different and carry different genes. The 44 non-sex chromosomes in humans are called **autosomes**.

Chromosomes and cell division

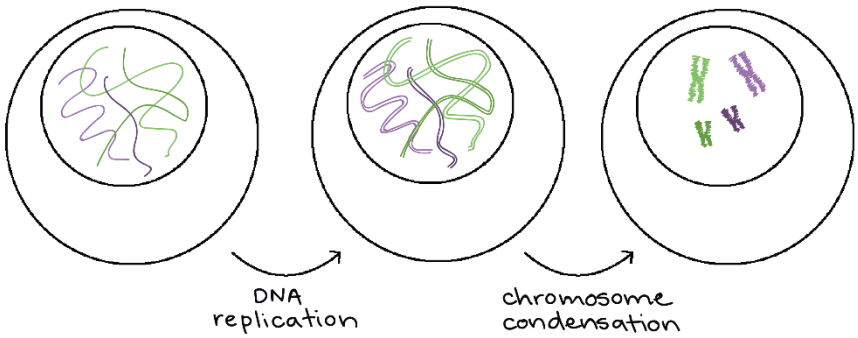
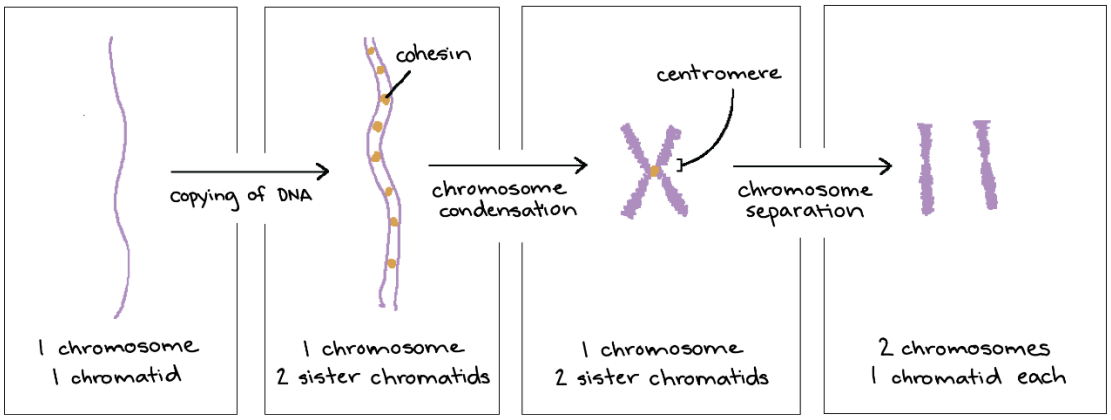


Image of a cell undergoing DNA replication (all the chromosomes in the nucleus are copied) and chromosome condensation (all the chromosomes become compact). In the first image, there are four decondensed, stringy chromosomes in the nucleus of the cell. After DNA replication, each chromosome now consists of two physically attached sister chromatids. After chromosome condensation, the chromosomes condense to form compact structures (still made up of two chromatids).

As a cell prepares to divide, it must make a copy of each of its chromosomes. The two copies of a chromosome are called **sister chromatids**. The sister chromatids are identical to one another and are attached to each other by proteins called **cohesins**. The attachment between sister chromatids is tightest at the **centromere**, a region of DNA that is important for their separation during later stages of cell division.

As long as the sister chromatids are connected at the centromere, they are still considered to be one chromosome. However, as soon as they are pulled apart during cell division, each is considered a separate chromosome.



What happens to a chromosome as a cell prepares to divide.

1. The chromosome consists of a single chromatid and is decondensed (long and string-like).
2. The DNA is copied. The chromosome now consists of two sister chromatids, which are connected by proteins called cohesins.
3. The chromosome condenses. It is still made up of two sister chromatids, but they are now short and compact rather than long and stringy. They are most tightly connected at the centromere region, which is the inward-pinching "waist" of the chromosome.
4. The chromatids are pulled apart. Each is now considered its own chromosome.

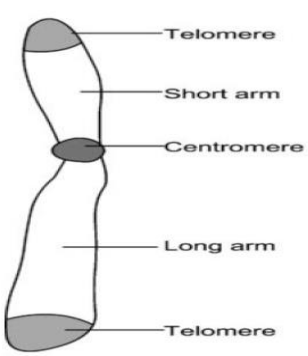
Why do cells put their chromosomes through this process of replication, condensation, and separation? The short answer is: to make sure that, during cell division, each new cell gets exactly one copy of each chromosome.

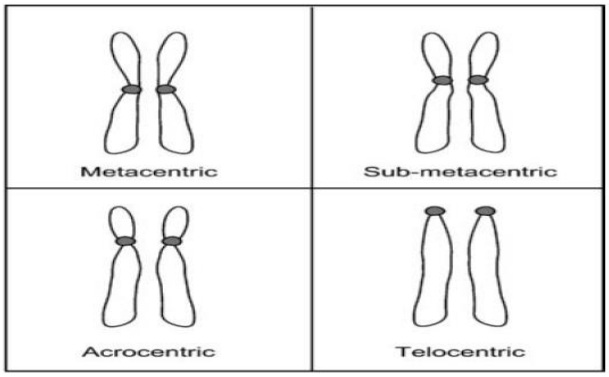
Chromosomes are thread-like structures located inside the nucleus of animal and plant cells. Each chromosome is made of protein and a single molecule of deoxyribonucleic acid (DNA). Passed from parents to offspring, DNA contains the specific instructions that make each type of living creature unique.

The term chromosome comes from the Greek words for color (chroma) and body (soma). Scientists gave this name to chromosomes because they are cell structures, or bodies, that are strongly stained by some colorful dyes used in research.

Structure of Chromosome

1. In eukarytoic cells, chromosomes are composed of single molecule of DNA with many copies of five types of histones.
2. Histones are proteins molecules and are rich in lysine and arginine residues, they are positively charged. Hence they bind tightly to the negatively-charged phosphates in the DNA sequence.
3. A small number of non-histone proteins are also present, these are mostly transcription factors. Transcription factors regulate which parts of DNA to be transcribed into RNA.
4. During most of the cell’s life cycle, chromosomes are elongated and cannot be observed under the microscope.
5. During the S phase of the mitotic cell cycle the chromosomes are duplicated.
6. At the beginning of mitosis the chromosomes are duplicated and they begin to condense into short structures which can be stained and observed easily under the light microscope.





7. These duplicated condensed chromosomes are known as dyads.
8. The duplicated chromosomes are held together at the region of centromeres.
9. The centromeres in humans are made of about 1-10 million base pairs of DNA.
10. The DNA of the centromere are mostly repetitive short sequences of DNA, the sequences are repeated over and over in tandem arrays.
11. The attached, duplicated chromosomes are commonly called sister chromatids.
12. Kinetochores are the attachment point for spindle fibers which helps to pull apart the sister chromatids as the mitosis process proceeds to anaphase stage. The kinetochores are a complex of about 80 different proteins.
13. The shorter arm of the two arms of the chromosome extending from the centromere is called the p arm and the longer arm is known the q arm.

Types of Chromosomes

Chromosomes are divided into two parts (p and q arms) with a constriction point called a centromere in the middle.

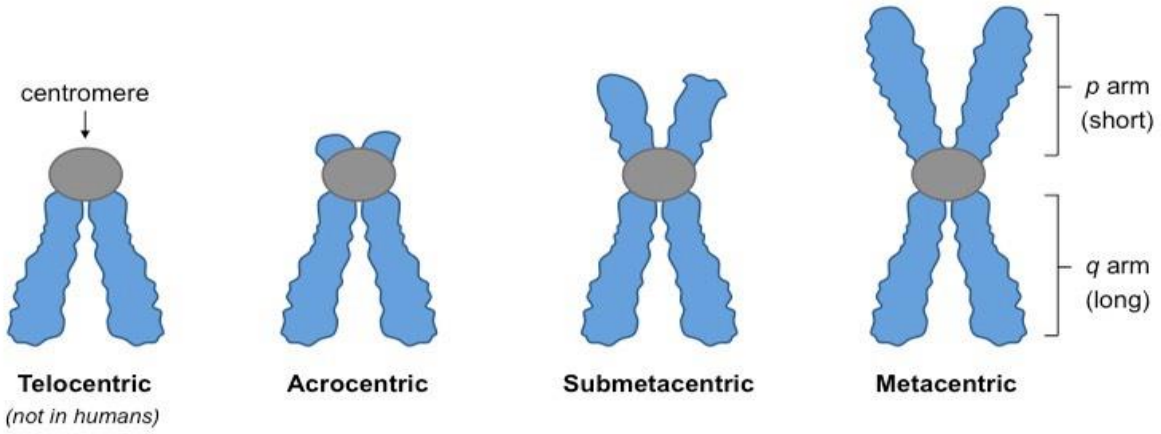
The centromere can be located in different positions and this forms the basis for the four different classes of chromosome:

Metacentric – centromere is in middle, meaning p and q arms are of comparable length (e.g. chromosomes 1, 3, 16, 19, 20)

Submetacentric – centromere off-centre, leading to shorter p arm relative to q arm (e.g. chromosomes 2, 4 – 12, 17, 18, X)

Acrocentric – centromere severely off-set from centre, leading to much shorter p arm (e.g. chromosomes 13 – 15, 21, 22, Y)

Telocentric – centromere found at end of chromosome, meaning no p arm exists (chromosome not found in humans)



GIANT CHROMOSOMES

These chromosomes are larger in size and are called giant chromosomes.

1. Polytene/Salivary Gland Chromosome 2. Lampbrush Chromosome

1. POLYTENE CHROMOSOMES

1.1 HISTORY

- An Italian cytologist **E.G. Balbiani** (1881) had 1st observed peculiar structure in the nuclei of certain secretory cells.
- Recognized as the chromosome by Theophilus Painter, Ernit Heitz and H.Bauer.
- Since, these chromosomes were discovered in the salivary gland cells, they are called as "**Salivary Gland Chromosomes**".
- The present name polytene chromosome was suggested by kollar due to the occurrence of **many chromonemata** (DNA) in them.
- **Bridges** (~1936) 1st constructed a salivary chromosome map of *D melanogaster* and found 5000 special bands in polytene chromosomes.
- Sutton worked on polytene chromosomes of Anapheles mosquitoes.
- Riandin worked on polytene chromosomes of tse-tse fly.

1.2 OCCURRENCE

- Polytene chromosomes commonly occur at the **diplotene stage** (meiotic division).
- These chromosomes have been observed in **salivary glands cells, Malpighian tubules, ovarian nurse cells and gut epithelial cells of the larvae of dipteran species** (*Drosophila*, chironomus, sciara and Rhyncosciara).
- These have also been reported from suspensor cells of developing embryos in leguminous plants.
- The Polytene Chromosomes are visible during interphase and prophase of mitosis.

1.3 REASON FOR GAINT STRUCTURE

- Drosophila and related insects, metabolically active tissues such as the salivary glands and intestines grow by an increase in the size of, rather than the number of their constituent cells. This process generates giant cells whose volumes are thousands of times greater than normal. Even the nucleic acids are 1000 times higher in quantity than normal cells.
- The development of giant cells is accompanied by successive rounds of DNA replications.
- As this DNA replication occurs in cells that are not dividing, the newly synthesized chromatids accumulate in each nucleus and live up in parallel to form multistranded structures called polytene chromosomes.
- Polytene chromosomes arise by repeated cycle of DNA duplication without nuclear division (uninterrupted by separation of the daughter chromosomes as the centromeric DNA remains unreplicated).
- Polyteny of giant chromosome is achieved by **ENDO-RE-DUPLICATION** i.e., replication of chromosomes DNA several times without complete nuclear division, and without cytokinesis.
- In the process of endo-re-duplication, the nuclear envelope doesn't rupture and no spindle formation takes place.

Example:
1. In *Drosophila*, 10 times endoduplication results >210=1024 thread like structure in each chromosome.

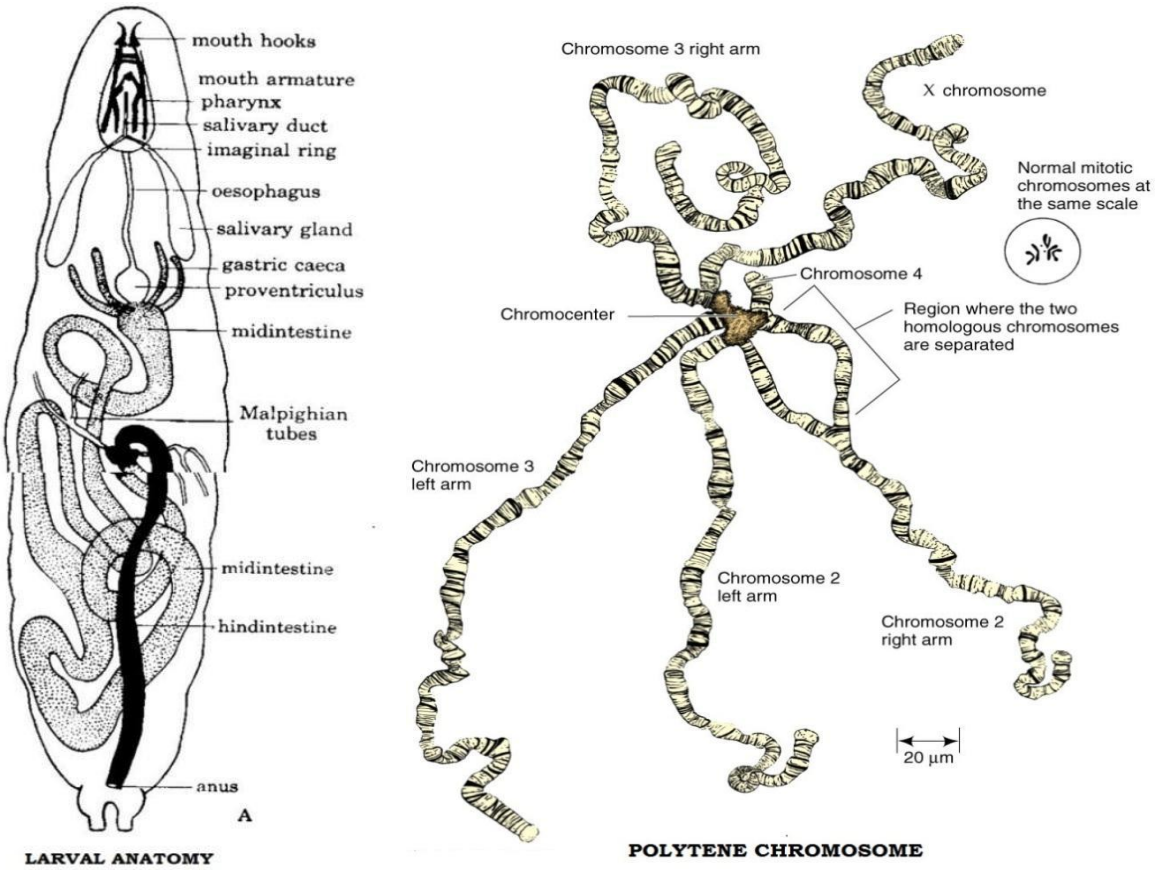
2. In chironomus, 13-14 times endoduplication results >16,000 chromonemata.

- Hence, these chromosomes are enormous structures measuring hundreds of micrometers in length and several micrometers in width. Roughly ten times longer and a hundred times wider than the metaphase chromosomes of typical eukaryotic cells.
- The polytene chromosomes are **2000 um in length** (7.5 um in somatic cells).

1.4 STRUCTURAL ORGANIZATION

- Polytene chromosomes consist of a large number of partially replicated chromosomes neatly stuck together in lateral array.

- In Drosophila, hetero-chromatinised centromere of all Chromosomes coalesces in a "**CHROMOCENTRE**".
- The Polytene Chromosomes are found in the form of **6 radiating arms** from chromocentre (**5 long and 1 short arm)**
  - X-chromosome (longest arm)
- 2R (II-chromosome Right arm)
  3. 2L (II-chromosome Left arm)]
  4. 3R (III-chromosome Right arm)



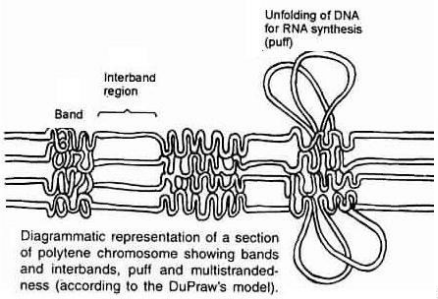
5. 3L (III-chromosome Left arm)
6. IV-chromosome (Shortest arm)
7. Y-Chromosome is not visualized as they are completely fused with chromocenter and they are totally heterochromatin.

BANDS AND INTERBANDS

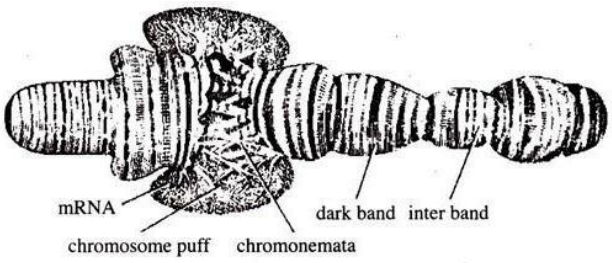
- When these chromosomes are treated with chromosomal stains and examined under microscope, an alternating pattern of dark (bands) and light (inter-bands) pattern is seen.

- The alignment of morphology, in which a series of **dark transverse bands** (higher coiling of chromonemata) alternate with **clear zone** called **inter-bands** (low coiling).
- 85% of DNA - band region
- 15% of DNA - inter-band region
- *Drosophila melanogaster* has ~5000 bands and ~5000 interbands per genome
- Each band and inter-band represent a set of 1024 identical DNA sequences arranged in file.
- The average band contains some 80,000 base pairs of DNA enough to encode a single polypeptide chain.
- The bands might contain several genes (1-7 genes), which give rise to independent transcripts and are separated by introns.
- Band sizes vary tremendously.

- The different staining properties of the bands and inter-bands are highly suggestive of difference states of compaction and organization of the chromatin in these regions.
- The cross **banding pattern** of each polytene chromosome is a **constant** characteristic within a **species** and helps for **chromosome mapping during cytogenetic studies**.



Diagrammatic representation of a section of polytene chromosome showing bands and interbands, puff and multistrandedness (according to the DuPraw's model).



Polytene chromosome of an insect, showing bands and interbands and a puff or Balbiani ring.

CHROMOSOMAL PUFFS /BALBIANI RINGS

- The bands undergo morphological and biochemical changes related to their gene activity.
- Activation of the genes of a band causes the compact chromatin strands to **uncoil** and expand outward, resulting in a chromosomal puff.
- Puffs consist of DNA loops that are less condensed than the DNA of bands elsewhere in the chromosome.
- Puffs are **active sites of gene transcription**
- As the Drosophila larva proceeds through development, each of the polytene chromosomes in salivary gland nuclei undergoes reproducible changes in puffing patterns under the control of insect steroid hormone called **ecdysone**.
- Condensation and de-condensation at puffs correlate with the enhancement of transcriptional activity at these sites.
- This can be shown by briefly labeling cells with a radioactive precursor of RNA (3H-Uridine) and localizing the newly made transcripts by autoradiography. Whereas a compact DNA band synthesizes very little RNA, intense labeling occurs over the largest puffs.
- Use of antibodies directed against various nuclear proteins can show that molecules such that molecules such as RNA polymerase, hnRNA proteins, snRNPs, and topoisomerases specially become concentrated in the puff region.