

Module1-Lecture 1

Prokaryotic and Eukaryotic cells

To venture into biology lets start with the cell!!!

In this chapter we will learn about what is a cell and further explore what a prokaryotic and eukaryotic cell is.

The cell was first seen by Robert Hooke in 1665 using a primitive, compound microscope. He observed very thin slices of cork and saw a multitude of tiny structures that he resembled to walled compartments of a monk. Hence, named them cells. Hooke's description of these cells was published in *Micrographia*. The cell is smallest unit of a living system and fall in the microscopic range of 1 to 100 μm . They attain various shapes and sizes to attain variety of functions. The understanding of cell is necessary to understand the structure and function of a living organism. One of most important characteristics of cell is ability to divide. The existence of a cell indicates that it has evolved from an already existing cell and further it can give rise to a new cell. This was first stated by Theodor Schwann. Pioneering work by Theodor Schwann, Matthias Jakob Schleiden on cells, gave birth to the cell theory. Their theory states:

1. All living things are made of cells.
2. Cells are the basic building units of life.
3. New cells are created by old cells dividing into two.

In 1855, Rudolf Virchow added another point to the theory and concluded that all cells come from pre-existing cells, thus completing the classical cell theory. The cell theory holds true for all living things, no matter how big or small, or how simple or complex. Viruses are exception to the cell theory. Cells are common to all living beings, and provide information about all forms of life. Because all cells come from existing cells, scientists can study cells to learn about growth, reproduction, and all other functions that

living things perform. By learning about cells and how they function, we can learn about all types of living things.

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 complexity. 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. These will be studied in detail in the upcoming sections.

Prokaryotic cells

Prokaryote means before nucleus in Greek. They include all cells which lack nucleus and other membrane bound organelles. Mycoplasma, virus, bacteria and cyanobacteria or blue-green algae are prokaryotes.

Most prokaryotes range between 1 μm to 10 μm , but they can vary in size from 0.2 μm to 750 μm (*Thiomargarita namibiensis*). They belong to two taxonomic domains which are the bacteria and the archaea. Most prokaryotes are unicellular, exceptions being myxobacteria which have multicellular stages in their life cycles. They are membrane bound mostly unicellular organisms lacking any internal membrane bound organelles. A typical prokaryotic cell is schematically illustrated in Figure 1. Though prokaryotes lack cell organelles they harbor few internal structures, such as the cytoskeletons, ribosomes, which translate mRNA to proteins. Membranous organelles are known in some groups of prokaryotes, such as vacuoles or membrane systems devoted to special metabolic properties, e.g., photosynthesis or chemolithotrophy. In addition, some species also contain protein-enclosed microcompartments, which have distinct physiological roles (carboxysomes or gas vacuoles).

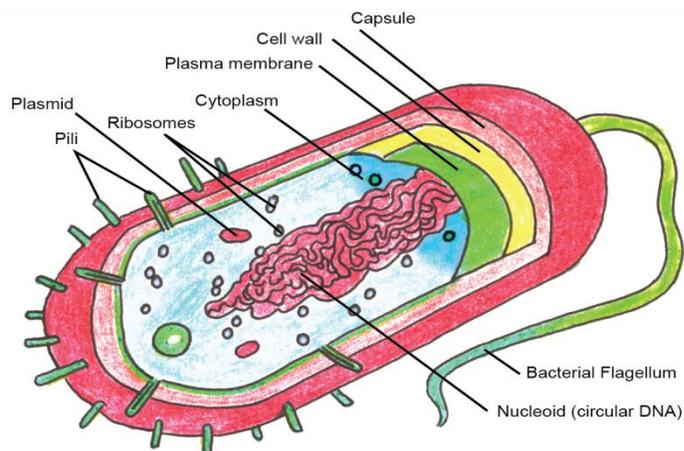


Figure 1: Schematic diagram of a prokaryotic cell

The individual structures depicted in Figure 1 are as follows and details will be discussed in forthcoming chapters:

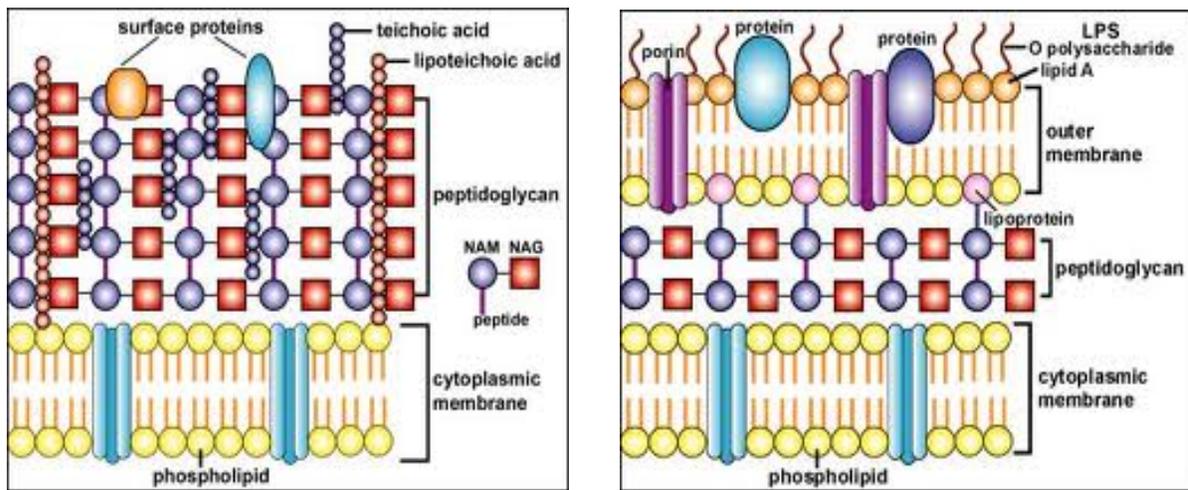
Flagella: It is a long, whip-like protrusion found in most prokaryotes that aids in cellular locomotion. Besides its main function of locomotion it also often functions as a sensory organelle, being sensitive to chemicals and temperatures outside the cell.

Capsule: The capsule is found in some bacterial cells, this additional outer covering protects the cell when it is engulfed by phagocytes and by viruses, assists in retaining moisture, and helps the cell adhere to surfaces and nutrients. The capsule is found most commonly among Gram-negative bacteria. *Escherichia coli*, *Klebsiella pneumoniae*, *Haemophilus influenzae*, *Pseudomonas aeruginosa* and *Salmonella* are some examples Gram-negative bacteria possessing capsules. Whereas examples of Gram positive bacteria are *Bacillus megaterium*, *Streptococcus pneumoniae*, *Streptococcus pyogenes*.

Cell wall: Cell wall is the outermost layer of most cells that protects the bacterial cell and gives it shape. One exception is Mycoplasma which lacks cell wall. Bacterial cell walls are made of peptidoglycan which is made from polysaccharide chains cross-linked by unusual peptides containing D-amino acids. Bacterial cell walls are different from the cell walls of plants and fungi which are made of cellulose and chitin, respectively. The cell wall of bacteria is also distinct from that of Archaea, which do not contain peptidoglycan.

The cell wall is essential to the survival of many bacteria. The antibiotic penicillin is able to kill bacteria by preventing the cross-linking of peptidoglycan and this causes the cell wall to weaken and lyse. Lysozyme enzyme can also damage bacterial cell walls.

There are broadly speaking two different types of cell wall in bacteria, called Gram-positive and Gram-negative (Figure 2). The names originate from the reaction of cells to the Gram stain, a test long-employed for the classification of bacterial species. Gram-positive bacteria possess a thick cell wall containing many layers of peptidoglycan and teichoic acids. In contrast, Gram-negative bacteria have a relatively thin cell wall consisting of a few layers of peptidoglycan surrounded by a second lipid membrane containing lipopolysaccharides and lipoproteins. These differences in structure can produce differences in property as antibiotic susceptibility. For example vancomycin can kill only Gram-positive bacteria and is ineffective against Gram-negative pathogens, such as *Pseudomonas aeruginosa* or *Haemophilus influenzae*.



A: Gram positive cell wall

B: Gram negative cell wall

Figure 2: A: Gram positive bacterial cell wall B: gram negative bacterial cell wall

Cell membrane: Cell membrane surrounds the cell's cytoplasm and regulates the flow of substances in and out of the cell. It will be discussed in detail in one of the coming chapters.

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. The details will be discussed in forthcoming chapter.

Ribosomes: Ribosomes are the organelles of the cell responsible for protein synthesis. Details of ribosomes will be explained in coming chapter.

Nucleoid Region: The nucleoid region is possessed by a prokaryotic bacterial cell. It is the area of the cytoplasm that contains the bacterial DNA molecule.

Plasmids: The term plasmid was first introduced by the American molecular biologist Joshua Lederberg in 1952. A plasmid is a DNA molecule (mostly in bacteria) that is separate from, and can replicate independently of, the chromosomal DNA. They are double-stranded and circular. Plasmids usually occur naturally in bacteria, but are sometimes found in eukaryotic organisms. Their sizes vary from 1 to over 1,000 kbp. The number of identical plasmids in a single cell can range anywhere from one to thousands under some circumstances and it is represented by the copy number. Plasmids can be considered mobile because they are often associated with conjugation, a mechanism of horizontal gene transfer. Plasmids that can coexist within a bacterium are said to be compatible. Plasmids which cannot coexist are said to be incompatible and after a few generations are lost from the cell. Plasmids that encode their own transfer between bacteria are termed conjugative. Non-conjugative plasmids do not have these transfer genes but can be carried along by conjugative plasmids via a mobilisation site. Functionally they carry genes that code for a wide range of metabolic activities, enabling their host bacteria to degrade pollutant compounds, and produce antibacterial proteins. They can also harbour genes for virulence that help to increase pathogenicity of bacteria causing diseases such as plague, dysentery, anthrax and tetanus. They are also

responsible for the spread of antibiotic resistance genes that ultimately have an impact on the treatment of diseases. Plasmids are classified into the following types.

1. Fertility F-plasmids- These plasmids contain tra genes and are capable of conjugation.
2. Resistance (R) plasmids: They contain genes that can build a resistance against antibiotics or toxins and help bacteria produce pili.
3. Col plasmids: They contain genes that code for bacteriocins, proteins that can kill other bacteria.
4. Degradative plasmids: Degradative plasmids enable the metabolism of unusual substances, e.g. toluene and salicylic acid.
5. Virulence plasmids: These plasmids enable the bacterium to become pathogenic.

The other types of plasmids are:

1. *Yeast integrative plasmid (YIp)*: yeast vectors that rely on integration into the host chromosome for survival and replication.
2. *Yeast Replicative Plasmid (YRp)*: which transport a sequence of chromosomal DNA that includes an origin of replication. These plasmids are less stable, as they can *get lost* during the budding.

Pili: Pili are hair-like structures on the surface of the cell that help attach to other bacterial cells. Shorter pili called fimbriae help bacteria attach to various surfaces. A pilus is typically 6 to 7 nm in diameter. The types of pili are Conjugative pili and Type IV pili. Conjugative pili allow the transfer of DNA between bacteria, in the process of bacterial conjugation. Some pili, called type IV pili, generate motile forces.

Morphology of prokaryotic cells

Prokaryotic cells have various shapes; the four basic shapes are (Figure 3):

- Cocci - spherical
- Bacilli - rod-shaped
- Spirochaete - spiral-shaped
- Vibrio - comma-shaped

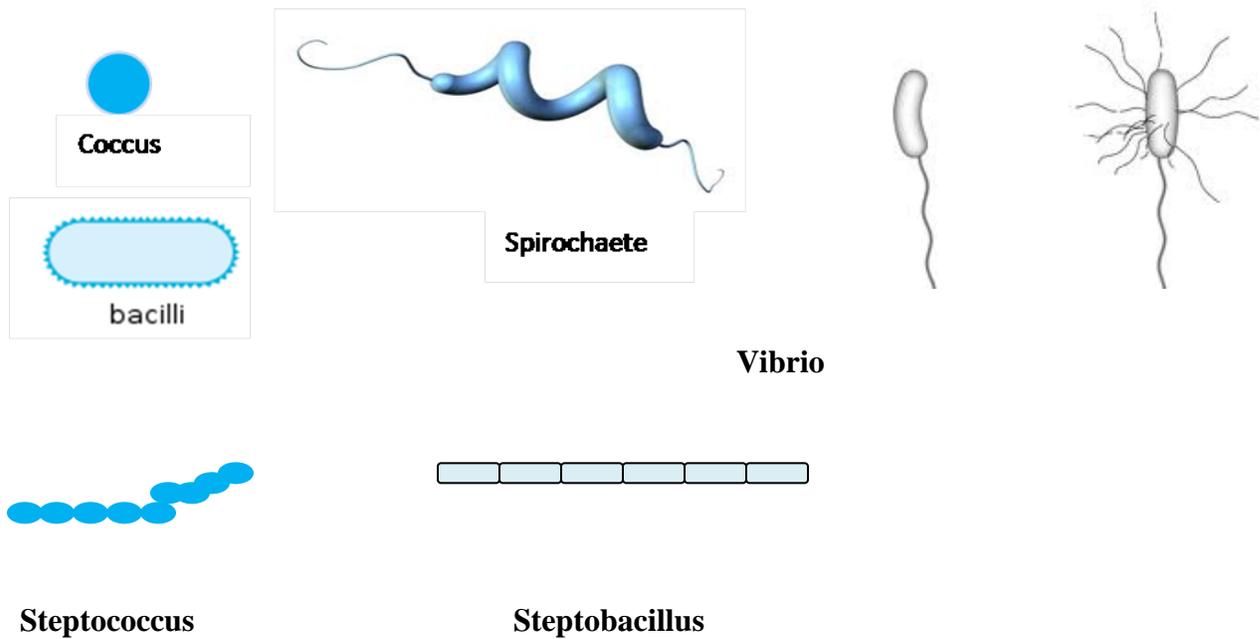


Figure 3: Morphology of prokaryotic cells

Milieu

Prokaryotes live in nearly all environments on Earth. Some archaea and bacteria thrive in extreme conditions, such as high temperatures (thermophiles) or high salinity (halophiles). Organisms such as these are referred to as extremophiles. Many archaea grow as plankton in the oceans. Symbiotic prokaryotes live in or on the bodies of other organisms, including humans.

Sociability

Prokaryotes are believed to be strictly unicellular though most can form stable aggregated communities in a stabilizing polymer matrix called “biofilms”. Cells in biofilms often show distinct patterns of gene expression (phenotypic differentiation) in time and space. Also, as with multicellular eukaryotes, these changes in expression appear as a result of quorum sensing or cell to cell signal transduction. Bacterial biofilms are often made up of approximately dome-shaped masses of bacteria and matrix separated by “voids” through which the medium (water) may flow relatively uninhibited and such system are termed as

microcolonies. The microcolonies may join together above the substratum to form a continuous layer, closing the network of channels separating microcolonies. Bacterial biofilms may be 100 times more resistant to antibiotics than free-living unicells and may be difficult to remove from surfaces once they have colonized them. Other aspects of bacterial cooperation like bacterial conjugation and quorum-sensing-mediated pathogenicity provide additional challenges to researchers and medical professionals seeking to treat the associated diseases.

Colony of bacteria

Most bacteria represent themselves in colonies. By colony we mean individual organisms of the same species living closely together in mutualism. All species in a colony are genetically equivalent. The shape of the colony can be circular and irregular. Bacterial colonies are frequently shiny and smooth in appearance. In microbiology, colony-forming unit (CFU) is a measure of viable bacteria in such colonies. If a bacterial cell like *Escherichia coli* divides every 20 minutes then after 30 cell divisions there will be 2^{30} or 1048576 cells in a colony.

Reproduction

Bacteria and archaea reproduce through asexual reproduction known as binary fission. Binary fission is an asexual mode of reproduction. During binary fission, the genomic DNA undergoes replication and the original cell is divided into two identical cells. Due to binary fission, all organisms in a colony are genetically equivalent (Figure 4). The process begins with DNA replication followed by DNA segregation, division site selection, invagination of the cell envelope and synthesis of new cell wall which are tightly controlled by cellular proteins. A key component of this division is the protein FtsZ which assemble into a ring-like structure at the center of a cell. Other components of the division apparatus then assemble at the FtsZ ring. This machinery is positioned so that division splits the cytoplasm and does not damage DNA in the process. As division occurs, the cytoplasm is cleaved in two, and new cell wall is synthesized.

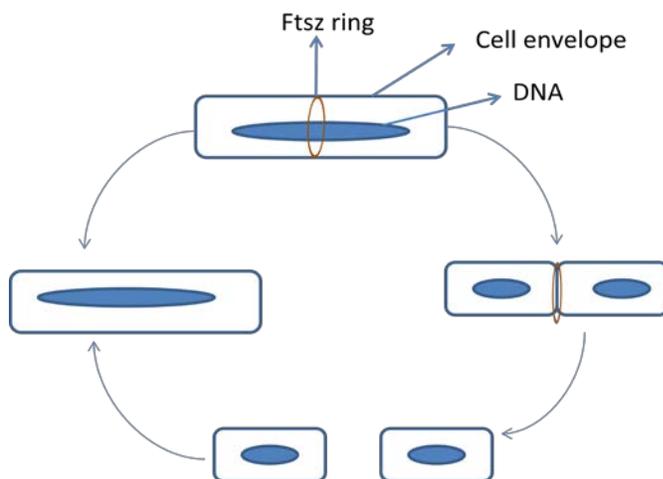


Figure 4: Binary fission in prokaryotes

Products/Application

Prokaryotes help manufacture yogurt, cheese, sour cream, antibiotics etc. They are the store house of many industrially important enzymes such as lipases, proteases, amylases which find use in detergent, paper and leather industries.

Eukaryote

A eukaryotic cell consists of membrane bound organelles. They belong to the taxa Eukaryota. All species of large complex organisms are eukaryotes, including animals, plants and fungi and most species of protist microorganisms. Eukaryotes appear to be monophyletic (organisms that form a clade) and make up one of the three domains of life. The two other domains, Bacteria and Archaea, are prokaryotes and have none of the above features. Eukaryotes represent a tiny minority of all living things; even in a human body there are 10 times more microbes than human cells. However, due to their much larger size their collective worldwide biomass is estimated at about equal to that of prokaryotes. Unlike prokaryotes, eukaryotic genome is enclosed in the nucleus surrounded by the nuclear membrane. Other than the nucleus many membrane bound organelles dwell in their cell cytoplasm. Cell division involves separating of the genome which is in the form of tightly packed condensed structure known as the chromosomes, through movements directed by the cytoskeleton.

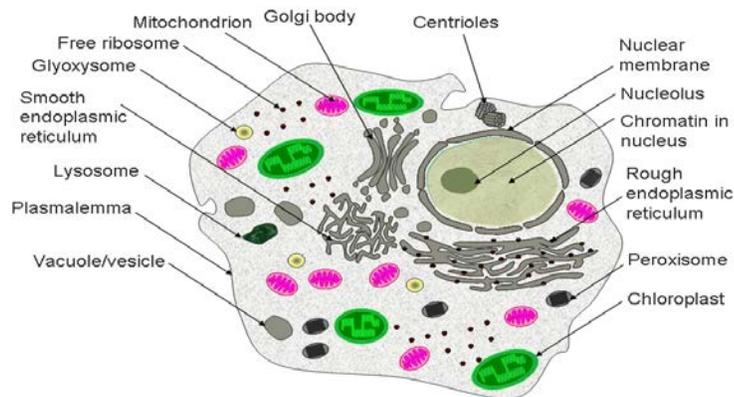


Figure 5 Eukaryotic cell:

Classification

The eukaryotes are composed of four kingdoms:

- Kingdom Protista
- Kingdom Fungi
- Kingdom Plantae
- Kingdom Animalia

Cell features

Eukaryotic cells are much larger than prokaryotic cells. Range between 10 to 100 micrometers. They have a variety of internal membranes and structures, called organelles, and a cytoskeleton composed of microtubules, microfilaments, and intermediate filaments, which play an important role in defining the cell's organization and shape. Eukaryotic DNA is divided into several linear bundles called chromosomes, which are separated by a microtubular spindle during nuclear division.

Internal membrane

Eukaryote cells include a variety of membrane-bound structures, collectively referred to as the endomembrane system involved in various functions. Simple compartments, called vesicles or vacuoles, can form by budding off other membranes. Many cells ingest food and other materials through a process of endocytosis, where the outer membrane invaginates and then pinches off to form a vesicle. It is probable that most other membrane-bound organelles are ultimately derived from such vesicles. The nucleus is surrounded by a double membrane (commonly referred to as a nuclear envelope), with pores that allow material to move in and out. Various tube and sheet like extensions of the nuclear membrane form what is called the endoplasmic reticulum or ER, which is involved in protein transport and maturation. It includes the rough ER where ribosomes are attached to synthesize proteins, which enter the interior space or lumen. Subsequently, they generally enter vesicles, which bud off from the smooth ER. In most eukaryotes, these protein-carrying vesicles are released and further modified in stacks of

flattened vesicles, called golgi bodies or dictyosomes. Vesicles may be specialized for various purposes. For instance, lysosomes contain enzymes that break down the contents of food vacuoles, and peroxisomes are used to break down peroxide, which is toxic otherwise. Many protozoa have contractile vacuoles, which collect and expel excess water, and extrusomes, which expel material used to deflect predators or capture prey. In multicellular organisms, hormones are often produced in vesicles. In higher plants, most of a cell's volume is taken up by a central vacuole, which primarily maintains its osmotic pressure. The individual cell organelles will be discussed in detail in the upcoming chapters.

Reproduction:

Nuclear division is often coordinated with cell division. This generally takes place by mitosis, a process that allows each daughter nucleus to receive one copy of each chromosome. In most eukaryotes, there is also a process of sexual reproduction, typically involving an alternation between haploid generations, wherein only one copy of each chromosome is present, and diploid generations, wherein two are present, occurring through nuclear fusion (syngamy) and meiosis. There is considerable variation in this pattern.

Association/hierarchy: In the plant and animal kingdom cells associate to form tissue, tissue to organs which finally makes the whole organism.

Prokaryotes versus Eukaryotes:

The difference between prokaryotes and Eukaryotes are detailed below. Eukaryotes have a smaller surface area to volume ratio than prokaryotes, and thus have lower metabolic rates and longer generation times. In some multicellular organisms, cells specialized for metabolism will have enlarged surface area, such as intestinal vili.

Table 1: Difference between prokaryotes and eukaryotes:

Characteristic	Prokaryotes	Eukaryotes
Size of cell	Typically 0.2-2.0 μm in diameter	Typically 10-100 μm in diameter
Nucleus	No nuclear membrane or nucleoli (nucleoid)	True nucleus, consisting of nuclear membrane & nucleoli
Membrane-enclosed organelles	Absent	Present; examples include lysosomes, Golgi complex, endoplasmic reticulum, mitochondria & chloroplasts
Flagella	Consist of two protein building blocks	Complex; consist of multiple microtubules
Glycocalyx	Present as a capsule or slime layer	Present in some cells that lack a cell wall
Cell wall	Usually present; chemically complex (typical bacterial cell wall includes peptidoglycan)	When present, chemically simple
Plasma membrane	No carbohydrates and generally lacks sterols	Sterols and carbohydrates that serve as receptors present
Cytoplasm	No cytoskeleton or cytoplasmic streaming	Cytoskeleton; cytoplasmic streaming
Ribosomes	Smaller size (70S)	Larger size (80S); smaller size (70S) in organelles
Chromosome (DNA) arrangement	Single circular chromosome; lacks histones	Multiple linear chromosomes with histones
Cell division	Binary fission	Mitosis
Sexual reproduction	No meiosis; transfer of DNA fragments only (conjugation)	Involves Meiosis

Phytoplanktons and zooplanktons:

Phytoplankton are photosynthesizing microscopic organisms that inhabit the upper sunlit layer of almost all oceans and bodies of fresh water and obtain their energy through photosynthesis. Interestingly Phytoplankton account for half of all photosynthetic activity on Earth. Some phytoplankton are bacteria, some are protists, and most are single-celled plants. Among the common kinds are cyanobacteria, silica-encased diatoms, dinoflagellates, green algae, and chalk-coated coccolithophores. Phytoplankton growth depends on the availability of carbon dioxide, sunlight, and nutrients. Phytoplankton require nutrients such as nitrate, phosphate, silicate, and calcium at various levels depending on the species. Some phytoplankton can fix nitrogen and can grow in areas where nitrate concentrations are low. They also require trace amounts of iron which limits phytoplankton growth in large areas of the ocean because iron concentrations are very low.

Zooplankton is a group of small protozoans and large metazoans. It includes holoplanktonic organisms whose complete life cycle lies within the plankton, as well as meroplanktonic organisms that spend part of their lives in the plankton before graduating to either the nekton or a sessile, benthic existence. Although zooplankton is primarily transported by ambient water currents, many have locomotion, used to avoid predators (as in diel vertical migration) or to increase prey encounter rate.

Module 1- Lecture 2

Plant and animal cells

In this chapter we will learn how similar and different are plant and animal cells.

Plant cells are eukaryotic cells that differ in several key aspects from the cells of other eukaryotic organisms. Their distinctive features include the following organelles:

1. Vacuole: It is present at the centre and is water-filled volume enclosed by a membrane known as the tonoplast. The function is to maintain the cell's turgor, pressure by controlling movement of molecules between the cytosol and sap, stores useful material and digests waste proteins and organelles.

2. Cell Wall: It is the extracellular structure surrounding plasma membrane. The cell wall is composed of cellulose, hemicellulose, pectin and in many cases lignin, is secreted by the protoplast on the outside of the cell membrane. This contrasts with the cell walls of fungi (which are made of chitin), and of bacteria, which are made of peptidoglycan. An important function of the cell wall is that it controls turgidity. The cell wall is divided into the primary cell wall and the secondary cell wall. The Primary cell wall: extremely elastic and the secondary cell wall forms around primary cell wall after growth are complete.

3. Plasmodesmata: Pores in the primary cell wall through which the plasmalemma and endoplasmic reticulum of adjacent cells are continuous.

4. Plastids: The plastids are chloroplasts, which contain chlorophyll and the biochemical systems for light harvesting and photosynthesis. A typical plant cell (e.g., in the palisade layer of a leaf) might contain as many as 50 chloroplasts. The other plastids are amyloplasts specialized for starch storage, elaioplasts specialized for fat storage, and chromoplasts specialized for synthesis and storage of pigments. As in mitochondria, which have a genome encoding 37 genes, plastids have their own genomes of about 100–120 unique genes and, it is presumed, arose as prokaryotic endosymbionts living in the cells of an early eukaryotic ancestor of the land plants and algae.

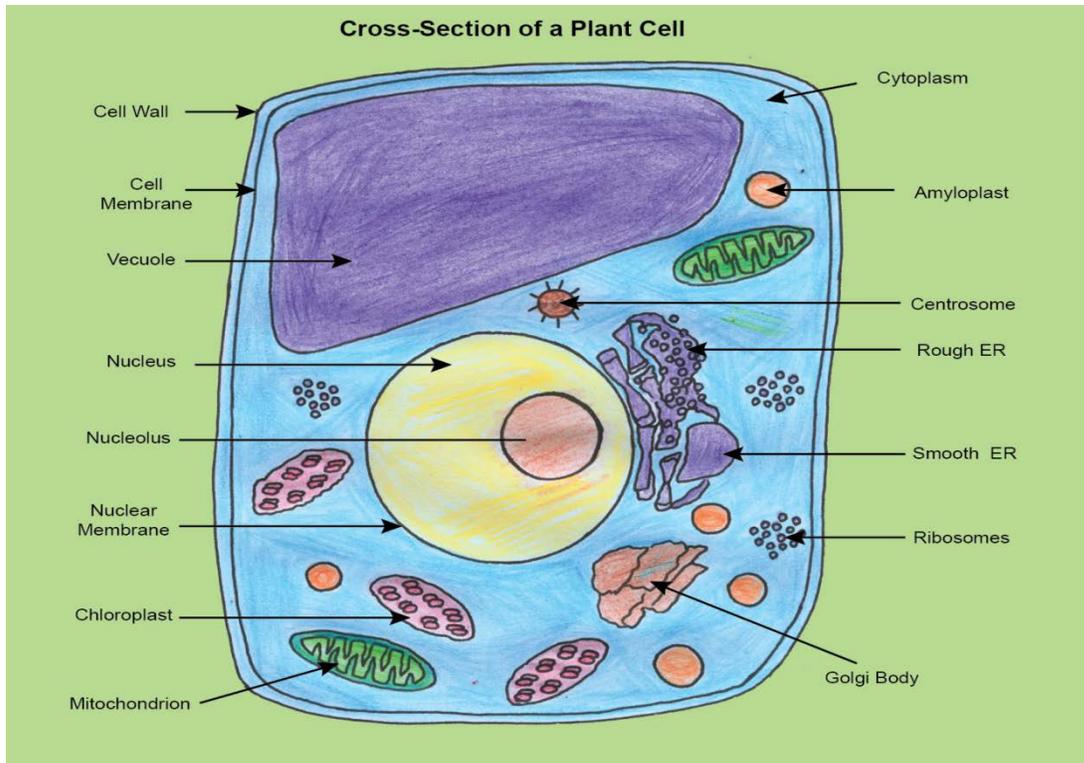


Figure 1: Schematic representation of a plant cell.

Plant cell types

Parenchyma cells: These are living cells that have diverse functions ranging from storage and support to photosynthesis and phloem loading (transfer cells). Apart from the xylem and phloem in its vascular bundles, leaves are composed mainly of parenchyma cells. Some parenchyma cells, as in the epidermis, are specialized for light penetration and focusing or regulation of gas exchange, but others are among the least specialized cells in plant tissue, and may remain totipotent, capable of dividing to produce new populations of undifferentiated cells, throughout their lives. Parenchyma cells have thin, permeable primary walls enabling the transport of small molecules between them, and their cytoplasm is responsible for a wide range of biochemical functions such as nectar secretion, or the manufacture of secondary products that discourage herbivory. Parenchyma cells that contain many chloroplasts and are concerned primarily with photosynthesis are called chlorenchyma cells. Others, such as the majority of the parenchyma cells in potato tubers and the seed cotyledons of legumes, have a storage function (Figure 2a).

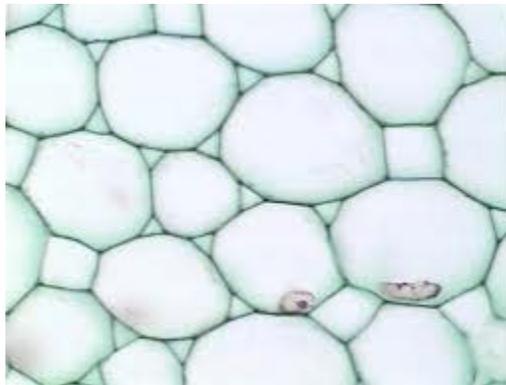


Figure 2a: Parenchyma cells which have thin primary cell wall.

Collenchyma cells: Collenchyma cells (Figure 2b) are alive at maturity and have only a primary wall. These cells mature from meristem derivatives that initially resemble parenchyma, but differences quickly become apparent. Plastids do not develop, and the secretory apparatus (ER and Golgi) proliferates to secrete additional primary wall. The wall is most commonly thickest at the corners, where three or more cells come in contact, and thinnest where only two cells come in contact, though other arrangements of the wall thickening are possible. Pectin and hemicellulose are the dominant constituents of collenchyma cell walls of dicotyledon angiosperms, which may contain as little as 20% of cellulose in *Petasites*. Collenchyma cells are typically quite elongated, and may divide transversely to give a septate appearance. The role of this cell type is to support the plant in axes still growing in length, and to confer flexibility and tensile strength on tissues. The primary wall lacks lignin that would make it tough and rigid, so this cell type provides what could be called plastic support – support that can hold a young stem or petiole into the air, but in cells that can be stretched as the cells around them elongate. Stretchable support (without elastic snap-back) is a good way to describe what collenchyma does. Parts of the strings in celery are collenchymas (Figure 2b).

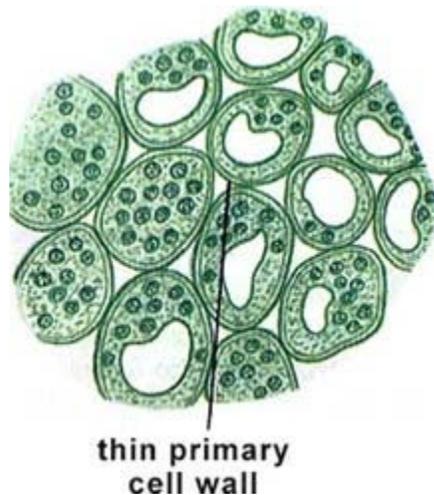


Figure 2b: Typical collenchyma cell.

Sclerenchyma cells: Sclerenchyma cells (from the Greek **skleros**, *hard*) are hard and tough cells with a function in mechanical support. They are of two broad types – sclereids or stone cells and fibres. The cells develop an extensive secondary cell wall that is laid down on the inside of the primary cell wall. The secondary wall is impregnated with lignin, making it hard and impermeable to water. Thus, these cells cannot survive for long' as they cannot exchange sufficient material to maintain active metabolism. Sclerenchyma cells are typically dead at functional maturity, and the cytoplasm is missing, leaving an empty central cavity.

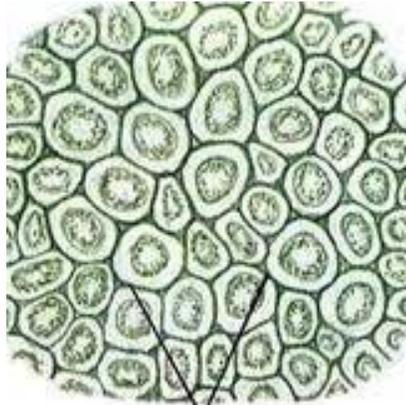


Figure 2c: Sclerenchyma cells with irregularly thickened cell wall.

Animal cells:

An animal cell is a form of eukaryotic cell that makes up many tissues in animals. Figure 7 depicts a typical animal cell. The animal cell is distinct from other eukaryotes, most notably plant cells, as they lack cell walls and chloroplasts, and they have smaller vacuoles. Due to the lack of a rigid cell wall, animal cells can adopt a variety of shapes, and a phagocytic cell can even engulf other structures. There are many different cell types. For instance, there are approximately 210 distinct cell types in the adult human body.

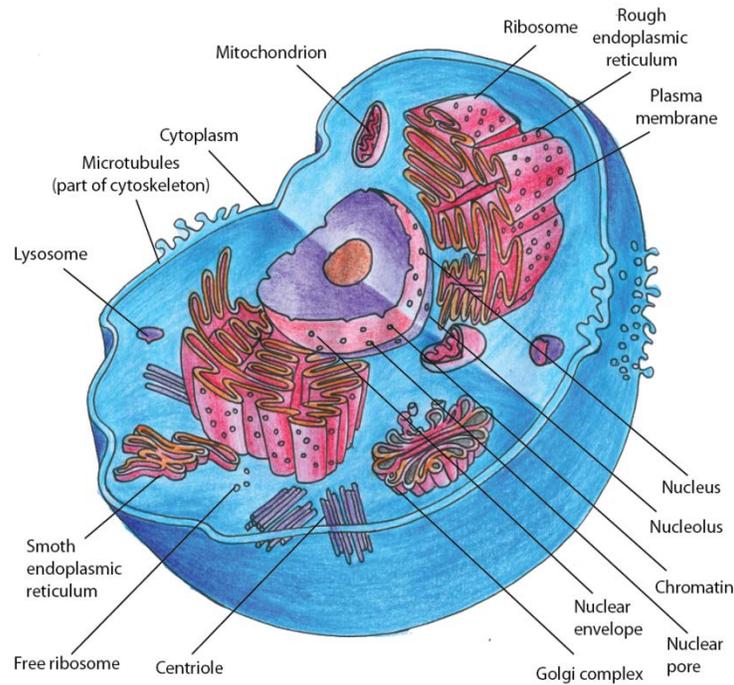


Figure 3: Schematic representation of a typical animal cell.

Cell organelles in animal cell:

Cell membrane: Plasma membrane is the thin layer of protein and fat that surrounds the cell, but is inside the cell wall. The cell membrane is semipermeable, allowing selective substances to pass into the cell and blocking others.

Nucleus: They are spherical body containing many organelles, including the nucleolus. The nucleus controls many of the functions of the cell (by controlling protein synthesis) and contains DNA (in chromosomes). The nucleus is surrounded by the nuclear membrane and possesses the nucleolus which is an organelle within the nucleus - it is where ribosomal RNA is produced.

Golgi apparatus: It is a flattened, layered, sac-like organelle involved in packaging proteins and carbohydrates into membrane-bound vesicles for export from the cell.

Ribosome and Endoplasmic reticulum: Ribosomes are small organelles composed of RNA-rich cytoplasmic granules that are sites of protein synthesis and Endoplasmic reticulum are the sites of protein maturation and they can be divided into the following types:

a. Rough endoplasmic reticulum: These are a vast system of interconnected, membranous, infolded and convoluted sacks that are located in the cell's cytoplasm (the ER is continuous with the outer nuclear membrane). Rough ER is covered with ribosomes that give it a rough appearance. Rough ER transport materials through the cell and produces proteins in sacks called cisternae (which are sent to the Golgi body, or inserted into the cell membrane).

b. Smooth endoplasmic reticulum: These are a vast system of interconnected, membranous, infolded and convoluted tubes that are located in the cell's cytoplasm (the ER is continuous with the outer nuclear membrane). The space within the ER is called the ER lumen. Smooth ER transport materials through the cell. It contains enzymes and produces and digests lipids (fats) and membrane proteins; smooth ER buds off from rough ER, moving the newly-made proteins and lipids to the Golgi body and membranes.

Mitochondria: These are spherical to rod-shaped organelles with a double membrane. The inner membrane is infolded many times, forming a series of projections (called cristae). The mitochondrion converts the energy stored in glucose into ATP (adenosine triphosphate) for the cell.

Lysosome: Lysosomes are cellular organelles that contain the hydrolase enzymes which breaks down waste materials and cellular debris. They can be described as the stomach of the cell. They are found in animal cells, while in yeast and plants the same roles are performed by lytic vacuoles. Lysosomes digest excess or worn-out organelles, food particles, and engulf viruses or bacteria. The membrane around a lysosome allows the digestive enzymes to work at the 4.5 pH they require. Lysosomes fuse with vacuoles and dispense their enzymes into the vacuoles, digesting their contents. They are created by the addition of hydrolytic enzymes to early endosomes from the Golgi apparatus.

Centrosome: They are small body located near the nucleus and has a dense center and radiating tubules. The centrosomes are the destination where microtubules are made. During mitosis, the centrosome divides and the two parts move to opposite sides of the dividing cell. Unlike the centrosomes in animal cells, plant cell centrosomes do not have centrioles.

Peroxisome

Peroxisomes are organelles that contain oxidative enzymes, such as D-amino acid oxidase, ureate oxidase, and catalase. They may resemble a lysosome, however, they are not formed in the Golgi complex. Peroxisomes are distinguished by a crystalline structure inside a sac which also contains amorphous gray material. They are self replicating, like the mitochondria. Components accumulate at a given site and they can be assembled into a peroxisome. Peroxisomes function to rid the body of toxic substances like hydrogen peroxide, or other metabolites. They are a major site of oxygen utilization and are numerous in the liver where toxic byproducts accumulate.

Vacuoles and vesicles

Vacuoles are single-membrane organelles that are essentially part of the outside that is located within the cell. The single membrane is known in plant cells as a tonoplast. Many organisms will use vacuoles as storage areas. Vesicles are much smaller than vacuoles and function in transporting materials both within and to the outside of the cell.

Table 1: Differences between Animal and Plant cell

S.No	Animal cell	Plant cell
1.	Animal cells are generally small in size.	Plant cells are larger than animal cells.
2.	Cell wall is absent.	The plasma membrane of plant cells is surrounded by a rigid cell wall of cellulose.
3.	Except the protozoan <i>Euglena</i> no animal cell possesses plastids.	Plastids are present.
4.	Vacuoles in animal cells are many and small.	Most mature plant cells have a large central sap vacuole.
5.	Animal cells have a single highly complex Golgi	Plant cells have many simpler units of and prominent Golgi apparatus. apparatus, called dictyosomes.
6.	Animal cells have centrosome and centrioles.	Plant cells lack centrosome and centrioles.

Some Typical cells:

Cyanobacteria: Cyanobacteria are aquatic and photosynthetic. They are quite small and usually unicellular, though they often grow in colonies large enough to see.

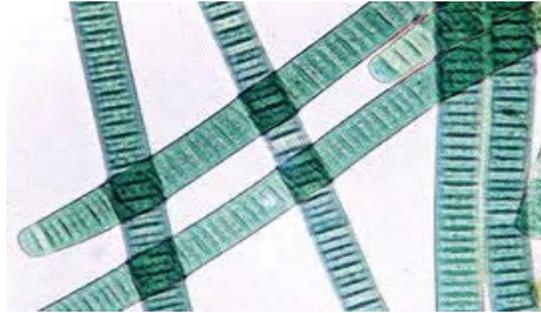


Figure 4: Cyanobacteria

Virus: A virus is a small infectious agent that can replicate only inside the living cells of organisms. Viruses infect all types of organisms, from animals and plants to bacteria and archaea. Their genetic material is DNA or RNA.

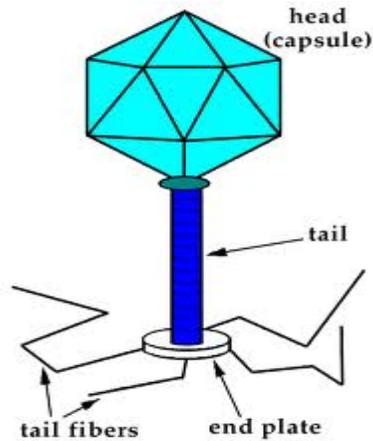


Figure 5: Virus

Red Blood Cells: Red blood cells are the most common type of blood cell and the vertebrate organism's principal means of delivering oxygen (O_2) to the body. They lack organelles like nucleus and mitochondria unlike typical eukaryotic cells.

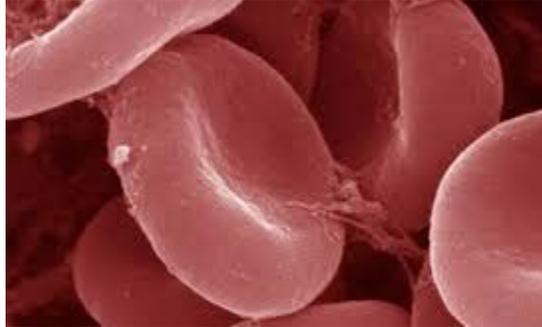


Figure 6: Red blood cell.

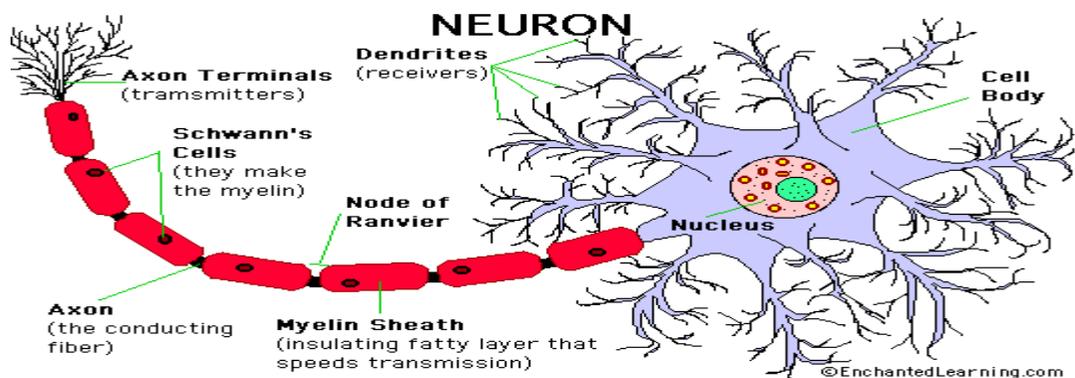


Figure 7: Nerve cell

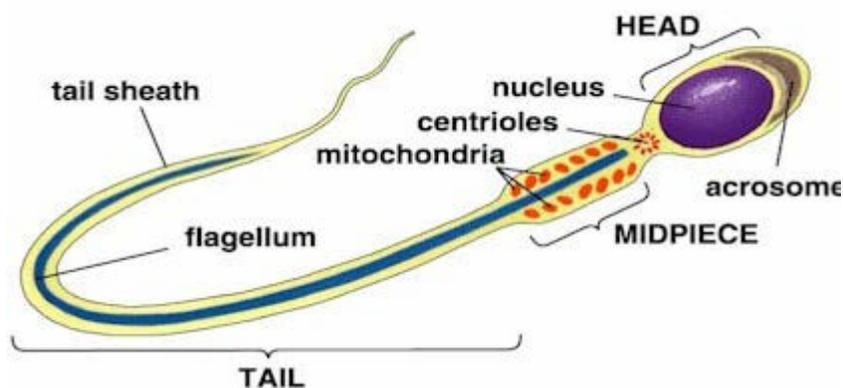


Figure 8: Human sperm cell

Interesting Facts:

1. There are anywhere from 75 to 100 trillion cells in the human body.
2. There are more bacterial cells in the body than human cells.
3. *Thiomargarita namibiensis* is the largest bacterium ever discovered, found in the ocean sediments of the continental shelf of Namibia and can be seen through the naked eye.
4. An unfertilized Ostrich egg is the largest single cell.
5. The smallest cell is a type of bacteria known as mycoplasma. Its diameter is 0.001 mm.
6. The Longest Cell in your body is the motor neuron cell, which is located in the spinal cord, near the central nervous system.

Module 1 Lecture 3

Principles of membrane organization, membrane proteins

Introduction

All living cells possess a cell membrane. These membranes serve to contain and protect cell components from the surroundings as well as regulate the transport of material into and out of the cell. Cell membranes are the selectively permeable lipid bilayers inclusive of membrane proteins which delimits all prokaryotic and eukaryotic cells. In prokaryotes and plants, the plasma membrane is an inner layer of protection bounded to the inner side of a rigid cell wall. Eukaryotes lack this external layer of protection or the cell wall. In eukaryotes the membrane also forms boundary of cell organelles. The cell membrane has been given different specific names based on their lipid and protein composition such as “sarcolemma” in myocytes and “oolemma” in oocytes. The plasma membrane is just 5-10nm wide thus cannot be detected under the light microscope. It can only be observed under the Transmission electron microscope as a trilaminar structure which is a layer of hydrophobic tails of phospholipids sandwiched between two layers of hydrophilic heads.

Functions

Functionally membranes take part in several cellular activities covering motility, energy transduction in lower unicellular organisms to immunorecognition in higher eukaryotes. The most valuable function is segregation of the cell into compartments. This functional diversity is due to the variability in lipid and protein composition of the membranes. The various functions can be summarized as given below.

1. Diffusion: Diffusion of small molecules such as carbon dioxide, oxygen (O₂), and water happens by passive transport.
2. Osmosis: Cell membrane is semipermeable thus it sets up an osmotic flow for solvent such as water, which can be transported across the membrane by osmosis.
3. Mediated Transport: Nutrients are moved across the membrane by special proteins called transport proteins or permeases which are quite specific, recognizing and transporting only a limited group of chemical substances, often even only a single substance.

4. Endocytosis: Endocytosis is the process in which cells absorb molecules by engulfing them small molecules and ions and macromolecules through active transport which requires ATP.

5. Exocytosis: The plasma membrane can extrude its contents to the surrounding medium to remove undigested residues of substances brought in by endocytosis, to secrete substances such as hormones and enzymes, and to transport a substance completely across a cellular barrier.

6. Cell adhesion.

7. Cell signaling.

Theories:

Quincke first perceived the lipid nature of the cell membranes and proposed it to be less than 100 nm thick. With time many researchers have proposed models for cell membrane.

In 1935, Danielli and Davson, proposed a model, called sandwich model, for membrane structure in which a lipid bilayer was coated on its either side with hydrated proteins (globular proteins). Mutual attraction between the hydrocarbon chains of the lipids and electrostatic forces between the protein and the “head” of the lipid molecules, were thought to maintain the stability of the membrane. From the speed at which various molecules penetrate the membrane, they predicted the lipid bilayer to be about 6.0 nm in thickness, and each of the protein layer of about 1.0 nm thickness, giving a total thickness of about 8.0 nm. The Danielli-Davson model got support from electron microscopy. Electron micrographs of the plasma membrane showed that it consists of two dark layers (electron dense granular protein layers), both separated by a lighter area in between (the central clear area of lipid bilayer). The total thickness of the membranes too turned out to be about 7.5 nm.

Currently, the most accepted model for cell membrane is fluid mosaic model proposed by S.J.Singer and G.L.Nicolson (1972). According to this model, the plasma membrane contains a bimolecular lipid layer, both surfaces of which are interrupted by protein molecules. Proteins occur in the form of globular molecules and they are dotted about here and there in a mosaic pattern (**see Figure 1**). Some proteins are attached at the polar surface of the lipid (i.e., the extrinsic proteins); while others (i.e., integral proteins) either

partially penetrate the bilayer or span the membrane entirely to stick out on both sides (called transmembrane proteins). Further, the peripheral proteins and those parts of the integral proteins that stick on the outer surface (i.e., ectoproteins) frequently contain chains of sugar or oligosaccharides (i.e., they are glycoproteins). Likewise, some lipids of outer surface are glycolipids.

The fluid-mosaic membrane is thought to be a far less rigid than was originally supposed.

In fact, experiments on its viscosity suggest that it is of a fluid consistency rather like the oil, and that there is a considerable sideways movement of the lipid and protein molecules within it. On account of its fluidity and the mosaic arrangement of protein molecules, this model of membrane structure is known as the “fluid mosaic model” (i.e., it describes both properties and organization of the membrane). The fluid mosaic model is found to be applied to all biological membranes in general, and it is seen as a dynamic, ever-changing structure. The proteins are present not to give it strength, but to serve as enzymes catalysing chemical reactions within the membrane and as pumps moving things across it.

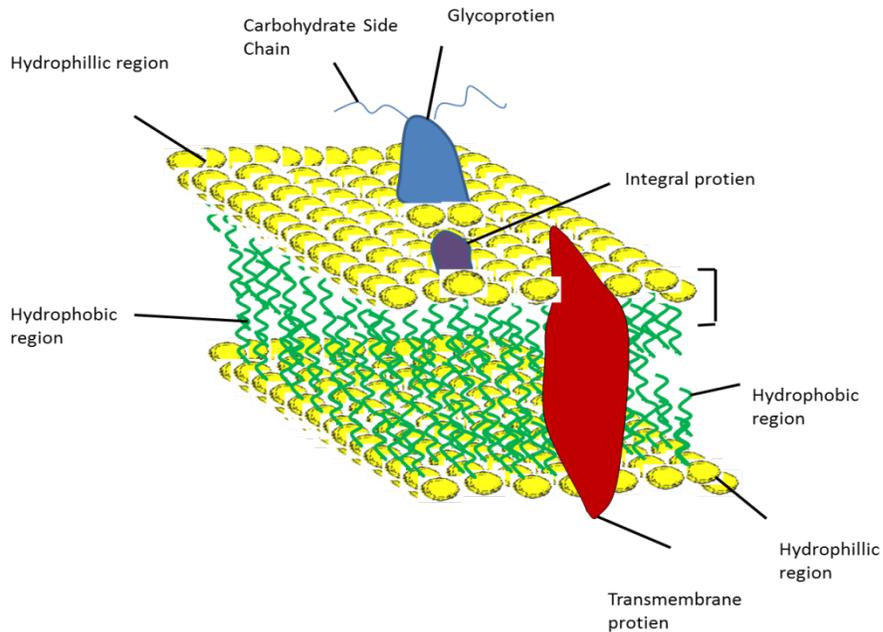


Figure 1: The architecture of the cell membrane

Biochemistry of the cell membrane

Membrane lipids

The cell membrane lipids are highly complex comprising of

- Phospholipids,
- Glycolipids,
- Cholesterols.

The major membrane phospholipids and glycolipids are phosphatidylcholine (PtdCho), phosphatidylethanolamine (PtdEtn), phosphatidylinositol (PtdIns) and phosphatidylserine (PtdSer) (Figure 2, Table 1). Eukaryotic membrane lipids are glycerophospholipids, sphingolipids, and sterols. Sphingolipids (SPs) and sterols enable eukaryotic cellular membranes with the property of vesicular trafficking important for the establishment and maintenance of distinct organelles. Mammalian cell membranes contain cholesterol which imparts stiffening and strengthening effect on the membrane, along with glycerophospholipids and sphingolipids. The head group of glycerophospholipids can vary, the fatty acids can differ in length (16- and 18-carbon fatty acids are the most common) Fatty acids can be saturated or unsaturated with the double bonds always in *cis* configuration in the later. The unsaturated fatty acids prevent tight packing of the fatty acid chains leading to lowering of melting temperature and increase in membrane fluidity. Also, the sphingolipids have the combinatorial propensity to create diversity by different ceramide backbones. Lipid molecules are free exhibit lateral diffusion along the layer in which they are present. However, the exchange of phospholipid molecules between intracellular and extracellular leaflets of the bilayer is a very slow process. The lipid composition, cellular architecture and function of cell membrane from unicellular bacteria to yeast and higher eukaryotes is presented in Table 2.

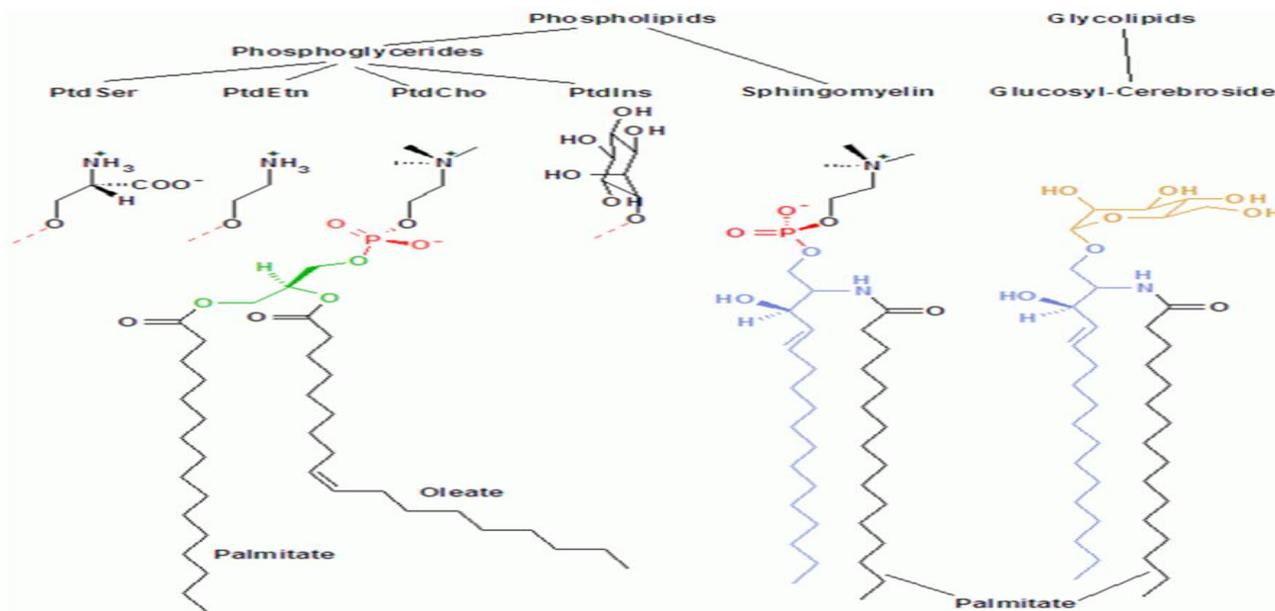


Figure 2 The major membrane phospholipids and glycolipids. The figure has been adapted from the “Membrane Organization and Lipid Rafts” by Kai Simons and Julio L. Sampaio, 2011, Cold Spring Harbor Laboratory Press.

Table 1 The composition of different membrane lipids

Type	Composition	Example/ Remarks
Phosphoglycerides	esters of phosphoric acid and a trifunctional alcohol-glycerol	Phosphatidate four common substituents for phosphatidate; Serine, ethanolamine, choline and inositol.
Sphingolipids	Phosphoglycerides where glycerol is substituted with sphingosine.	Sphingomyelin, Glycosphingolipid Found in particularly nerve cells and brain tissues

Table 2 The cellular architecture and function of cell membrane

Organism	Lipid composition	Membrane properties	Functionalities
Bacteria	Phosphatidylethanolamine and Phosphatidylglycerol	Robust Different shapes	Membrane protein incorporation
Yeast	Sphingolipids, Glycerophospholipids and Sterols	Robust Different shapes Complex organelle morphology	Membrane protein incorporation Membrane budding Vesicular trafficking
Higher Eukaryotes	Glycerophospholipids, sterols, and tissue-specific Sphingolipids	Robust Different shapes Complex organelle morphology Complex and specific cellular architecture	Membrane protein incorporation Membrane budding Vesicular trafficking Specific functions depending on the cell type

Role of Lipid Molecules in Maintaining Fluid Property of Membrane

Types of movements of lipid molecules.

In lipid monolayer flip-flop or transbilayer movement occurs once a month for any individual lipid molecule. However, in membranes where lipids are actively synthesized, such as smooth ER, there is a rapid flip-flop of specific lipid molecules across the bilayer and there are present certain membrane-bound enzymes, called phospholipid translocators like flippases to catalyze this activity. The other movement is lateral diffusion. Individual lipid molecules rotate very rapidly about their long axes and their hydrocarbon chains are flexible, the greatest degree of flexion occurring near the centre of the bilayer and the smallest adjacent to the polar head groups.

Role of unsaturated fats in increasing membrane fluidity.

A synthetic bilayer made from a single type of phospholipid changes from a liquid state to a rigid crystalline state at a characteristic freezing point. This change of state is called a phase transition

and the temperature at which it occurs becomes lower if the hydrocarbon chains are short or have double bonds. Double bonds in unsaturated hydrocarbon chains tend to increase the fluidity of a phospholipid bilayer by making it more difficult to pack the chains together. Thus, to maintain fluidity of the membrane, cells of organisms living at low temperatures have high proportions of unsaturated fatty acids in their membranes, than do cells at higher temperatures.

Role of cholesterol in maintaining fluidity of membrane

Eukaryotic plasma membranes are found to contain a large amount of cholesterol; up to one molecule for every phospholipid molecule. Cholesterol inhibits phase transition by preventing hydrocarbon chains from coming together and crystallizing. Cholesterol also tends to decrease the permeability of lipid bilayers to small water-soluble molecules and is thought to enhance both the flexibility and the mechanical stability of the bilayer.

Membrane proteins

In addition to the lipid bilayer, the cell membrane also contains a number of proteins. 35% of the genes in any genome encode membrane proteins, and many other proteins spend part of their lifetime bound to membranes. The amount of protein differs between species and according to function, however the typical amount in a cell membrane is 50%. Membrane proteins are free to move within the lipid bilayer as a result of its fluidity. Although this is true for most proteins, they can also be confined to certain areas of the bilayer with enzymes.

They can be classified into

- Integral (intrinsic)
- Peripheral (extrinsic)

which is based on the nature of the membrane-protein interactions (Figure 3). Integral proteins have one or more segments that are embedded in the phospholipid bilayer from four to several hundred residues long, extending into the aqueous medium on each side of the bilayer. The transmembrane embedded in the hydrophobic core of the bilayer are α

helices or multiple β strands interacting with the lipid bilayer with hydrophobic and ionic interactions. An example is Glycophorin which is a major erythrocyte membrane protein and bacteriorhodopsin, a protein found in a photosynthetic bacterium (Figure 3a, 3b). Glycophorin is a homodimer containing α helix in coiled-coiled conformation, composed of uncharged amino acids. Few positively charged amino acids (lysine and arginine) prevent it from slipping across the membrane by interacting with negatively charged phospholipid head groups. Most of these charged residues are adjacent to the cytosolic face of the lipid bilayer. Bacteriorhodopsins have serpentine membrane spanning domain. Other examples of seven-spanning membrane proteins include the opsins (eye proteins that absorb light), cell-surface receptors for many hormones, and receptors for odorous molecules. Some integral proteins are anchored to the exoplasmic face of the plasma membrane by a complex glycosylated phospholipid that is linked to the C-terminus. A common example of this type of anchor is glycosylphosphatidylinositol, which contains two fatty acyl groups, *N*-acetylglucosamine, mannose, and inositol for example alkaline phosphatase. Whereas some are attached by a hydrocarbon moiety covalently attached to a cysteine near the C-terminus. The most common anchors are prenyl, farnesyl, and geranylgeranyl groups.

Peripheral membrane proteins do not interact with the hydrophobic core and are bound to the membrane indirectly by interactions with integral membrane proteins or directly by interactions with lipid polar head groups. Peripheral proteins localized to the cytosolic face of the plasma membrane include the cytoskeletal proteins spectrin and actin in erythrocytes and the enzyme protein kinase C involved in cell signaling. An important group of peripheral membrane proteins are water-soluble enzymes that associate with the polar head groups of membrane phospholipids.

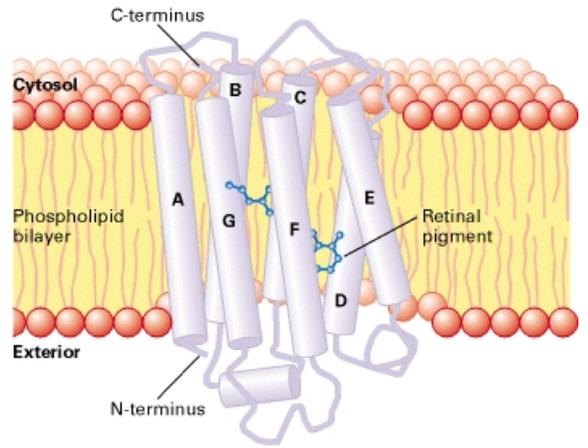
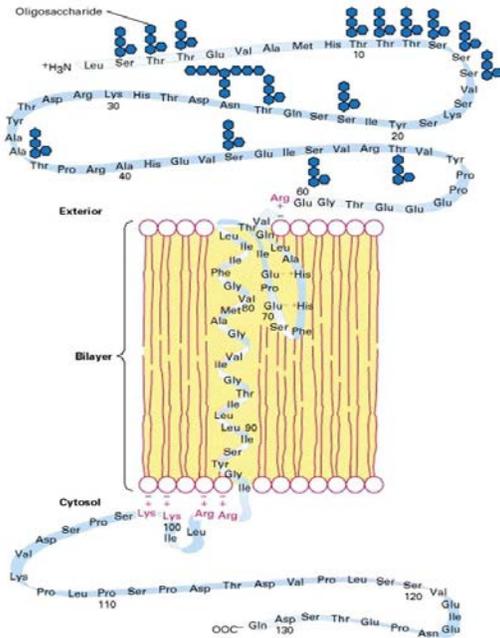


Figure 3a, 3b. Figure 3a This protein is a homodimer, but only one of its polypeptide chain is shown. Residues 62–95 are buried in the membrane, with the sequence from position 73 through 95 forming an α helix. The ionic interactions shown between positively charged arginine and lysine residues and negatively charged phospholipid head groups in the cytosolic and exoplasmic faces of the membrane are hypothetical. Both the amino-terminal segment of the molecule, located outside the cell, and the carboxy-terminal segment, located inside the cell, are rich in charged residues and polar uncharged residues, making these domains water-soluble. Note the numerous carbohydrate residues attached to amino acids in the exoplasmic domain. Adapted from V. T. Marchesi, H. Furthmayr, and M. Tomita, 1976, *Ann. Rev. Biochem.* 45:667.

Fig 3b The seven membrane-spanning α helices are labeled A–G. The retinal pigment is covalently attached to lysine 216 in helix G. The approximate position of the protein in the phospholipid bilayer is indicated. Adapted from R. Henderson et al., 1990, *J. Mol. Biol.* 213:899.