6th SEM B.Sc. Botany
CALICUT UNIVERSITY

Cell Biology & Biochemistry
2017 ADMISSION

Prepared by
Abdul Faisal P, Riya Rafeeque and Chandini, V. K.
Assistant professor
Department of Botany
CPA COLLEGE OF GLOBAL STUDIES, PUTHANATHANI

Syllabus
CELL BIOLOGY
Module – I.
1. Architecture of cells. Prokaryotic and Eukaryotic cells.
2. Structure and function of the following:
a. Cell membrane (fluid mosaic model),
b. Endoplasmic reticulum,
c. Golgi complex,
d. mitochondria
e. chloroplast,
f. Lysosomes
g. Glyoxisomes
h. Ribosomes
i. Cytoskeleton
j. Cytosol
k. Vacuole
3. Nucleus - Nuclear membrane; Nuclear pore complex; organization of interphase Nucleus; Euchromatin and heterochromatin; Nucleolus.
4. Chromosomes - Morphology, classification, Centromere and Telomere, Chemical Composition and organization.
Module-II
1. Special types of chromosomes –Polytene chromosomes, lampbrush chromosomes
2. Cell division - cell cycle - Mitosis & Meiosis – significance- molecular control of cell division
3. Chromosomal changes - structural aberrations: deletion, duplication, inversion, translocation - their meoitic consequences and significance
4. Numerical aberration - Defintion - Basic chromosome number (Genomic Number) Aneuploidy, Haploidy and Polyploidy - their meiotic behavior and significance.

Module I
Cell biology: Study of cell structure and function
Cell

- The cell is the smallest unit of living matter.
- The cell is the smallest unit having all the properties of life.
- All organisms are composed of structural and functional units of life called cells.
- The body of some organisms like bacteria, protozoans and some algae is made up of a single cell (Unicellular organisms) while the body of fungi, plants and animals are composed of many cells (Multicellular organisms).
- Cells vary in size and structure as they are specialized to perform different functions.
- But the basic components of the cell are common to all cells.

Discovery of cell

- Robert Hooke (1665), an English scientist, discovered and coined the term cell while examining a thin slice of cork under a self-designed compound microscope. The term cell was derived from a Latin word cellular (meaning little room or chamber).
- In 1672, Antony Van Leeuwenhoek observed bacteria, sperms and red blood corpuscles, all of which were cells.
- In 1831, Robert Brown, an Englishman observed that all cells had a centrally positioned body which he termed the nucleus.

What is a cell?

- Cell is the structural and functional unit of living organisms, enclosing a bit of protoplast consisting of numerous micro and macro organic and inorganic molecules, dissolved or suspended in colloidal or watery matrix.

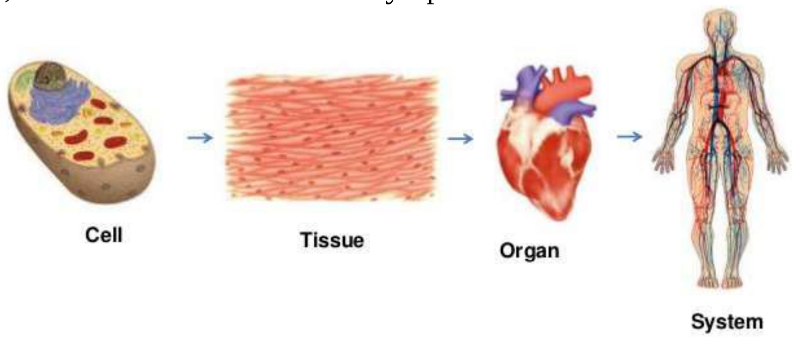
Cell theory

- The cell theory was jointly put forward by Schleiden and Schwann (1839) in their paper **"**Microscopic investigations on the similarity of structure and growth in animals and plants**"** : As follows
  1) All organisms are composed of one or more cells.
  2) Cells are the basic living units within organisms and the chemical reactions of life take place within cells.
  3) All cells arise from pre existing cells by division and are not formed de novo
- In 1855, a German medical doctor named Rudolph Virchow observed, under the microscope, cells dividing. He reasoned that all cells come from other pre-existing cells by cell division.

Modern cell theory

- The cell is the fundamental unit of structure and function in living organisms.
- New cells arise from pre-existing cells through division. All new cells contain the same amount and degree of genetic information as contained in the parent cell
- Energy flow occurs within cells.
- Cells contain hereditary information (DNA) which is passed from cell to cell during cell division.
- All cells are basically the same in chemical composition in organisms of similar species.
- All known living things are made up of one or more cells.
- Some organisms are made up of only one cell and are known as unicellular organisms. All life begins as a single cell.
- Others are multicellular, composed of a number of cells.
- The activity of an organism depends on the total activity of independent cells.

- Depending upon specific requirement, the cells get modified, e.g. elongated in muscle and nerve cells, loss of nucleus in RBCs or cytoplasm in outer skin cells.



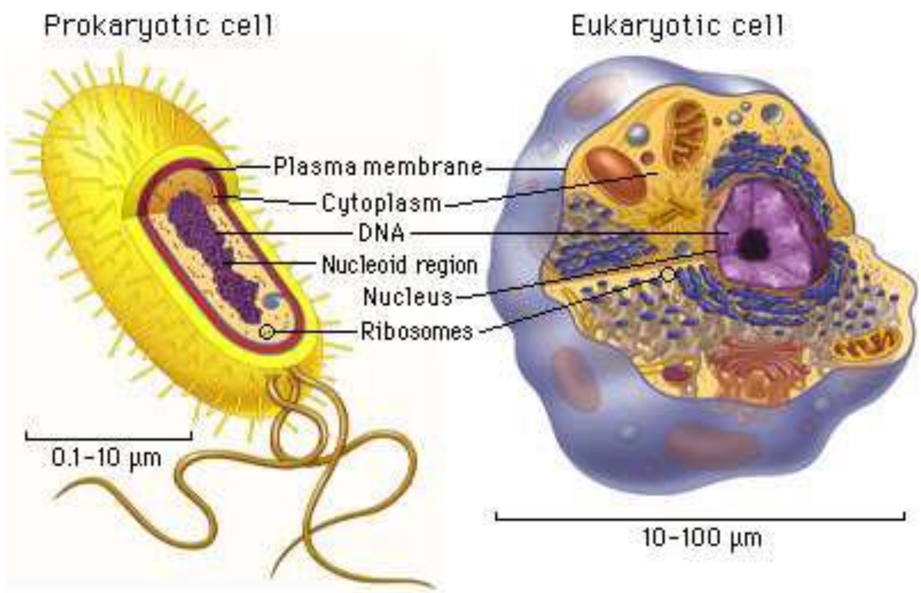
Similar cells join together to form tissues. Different tissues join together to form organs. Organs work together to form systems.

ORGANISMS SHOW VARIETY IN CELL NUMBER, SHAPE AND SIZE

- The organisms made up of a single cell are called unicellular organisms. These are capable of independent existence. The single cell carries all the functions like digestion, excretion, respiration, growth and reproduction. So, they are rightly called acellular organisms Eg: Amoeba, Euglena, Paramecium etc.
- The organisms made up of more than one cell are called multicellular organisms.
  In multicellular organisms the cells vary in their shape and size depending on their function. The cells are spherical, oval, polyhedral, discoidal, spindle shaped, cylindrical in shape. The shape of the cells varies with the functions they perform.
  Eg: Parenchyma cells – Polyhedral cells that perform storage function.
  Sclerenchyma cells – Spindle shaped cells that provide mechanical support
  White blood cells – Amoeboid cells that defend the body against pathogens
  Nerve cells – Long and branched that conduct nerve impulses
  Muscle cells – cylindrical or spindle shaped cells concerned with the movement of body parts.
- The size of the cell varies from few micrometers (µm) to few centimeters (cm). The size of bacteria varies from 0.1 to 0.5 µm. The smallest cell PPLO (Pleuro pneumonia like organism) is about 0.1 µ in diameter. The largest cell is an ostrich egg that measures 170 to 180 mm in diameter. Some Sclerenchyma fibres measure up to 60 cm in length. However the average size of the cell ranges from 0.5 to 10 µm in diameter.
- **Units of measurement**
  1cm = 10mm (millimeter), 1mm = 1000 µm (micrometers), 1 µm = 10000 A^0 (Angstrom), 10A^0 = 1nm (nanometer)

Type of cells

- Dougherty (1957) classified cells into prokaryotic (Pro meaning primitive, karyon meaning nucleus) and eukaryotic (Eu meaning true, Karyon meaning nucleus) types on the basis of structural organization of their nucleus.
- The cells which possess a primitive type of nucleus devoid of nuclear membrane are the prokaryotic cells. On the other hand, eukaryotic cells are those which possess a true, well organized nucleus having typical chromosomes and nuclear membrane.
- Dodge et al (1966) proposed a third type (Mesokaryotic) which can be placed in between prokaryotic and eukaryotic cells.

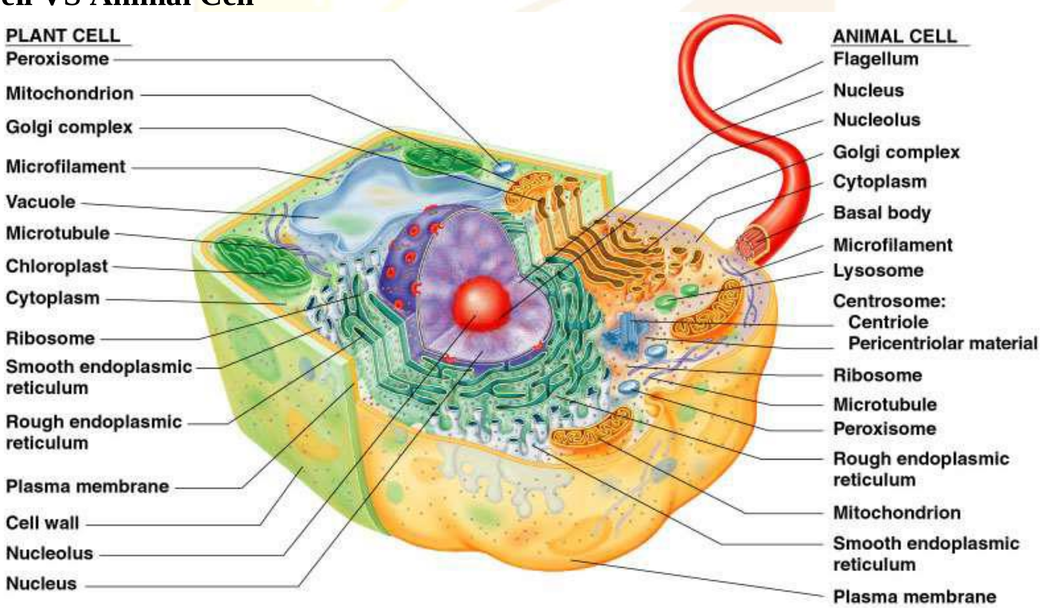


Difference between Prokaryotic and Eukaryotic cell

Character	Prokaryotic cell	Eukaryotic cell
Cell compartments	No compartments	Distinct compartments in the cell. i.e. the cytoplasm and the nucleus
Cell wall	Present, composed of amino sugars and muramic acid	Absent in animal cell, present in plant cell, composed of cellulose
Plasma membrane	Present, core of lipid bilayer with proteins embedded as mosaic	Present,lipid bilayer, with embedded proteins
Cell organelles	Absent, Enzymatic functions are carried by infoldings of plasma membrane- mesosomes	Different cell organelles present for different functions ,bound by extensions of plasma membrane
Respiratory system	Mesosome(part of plasma membrane)	Mitochondria
Capsule	If present , composed of mucopolysaccharides	Absent
Photosynthetic apparatus and chlorophyll	Photosynthetic pigments chlorophylls and carotenes on grana lamellae not enclosed by membrane, no plastid	Pigments present on lamellar system, enclosed by membrane in cytoplasm. plastids present in plant cells
Organization of the nucleus	Nucleus not distinct , It is in the form of nuclear zone (Nucloid)	Distinct nucleus

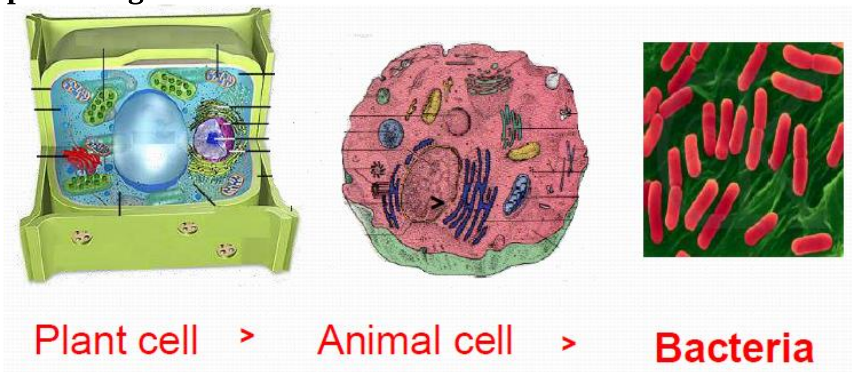
Character	Prokaryotic cell	Eukaryotic cell
Nuclear membrane	Absent	Well formed nuclear membrane
Nucleoplasm	Undifferentiated from cytoplasm	Denser and differentiated from cytoplasm by nuclear membrane
Hereditory material	Single naked strand of DNA / RNA Circular in shape.DNA not linked with Histone proteins	More than one strand of DNA & Histone protein inside nuclear membrane as chromosomes
Nucleolous	Absent	Present
Flagellum	Single,simple composed of protein flagellin No 9+2 fibrillar pattern	complex 9+2 fibrillar pattern composed of tubulin and other proteins
Cell division	Amitosis (Binary fisson) spindle not formed	Mitosis or meiosis Spindle formed
Ribosomes	70S (30S+50S)	80 S (40S+60S)
Cytoplasmic movements	Rare or absent	Often occurs
Vacuoles	Absent	Present
Lysosome	Absent	Present
Growth	Can grow both under aerobic and anaerobic conditions	Can grow only under aerobic condition
Size	1-10 μm	10-100 μm

Plant Cell VS Animal Cell



(a) Highly schematic diagram of a composite eukaryotic cell, half plant and half animal

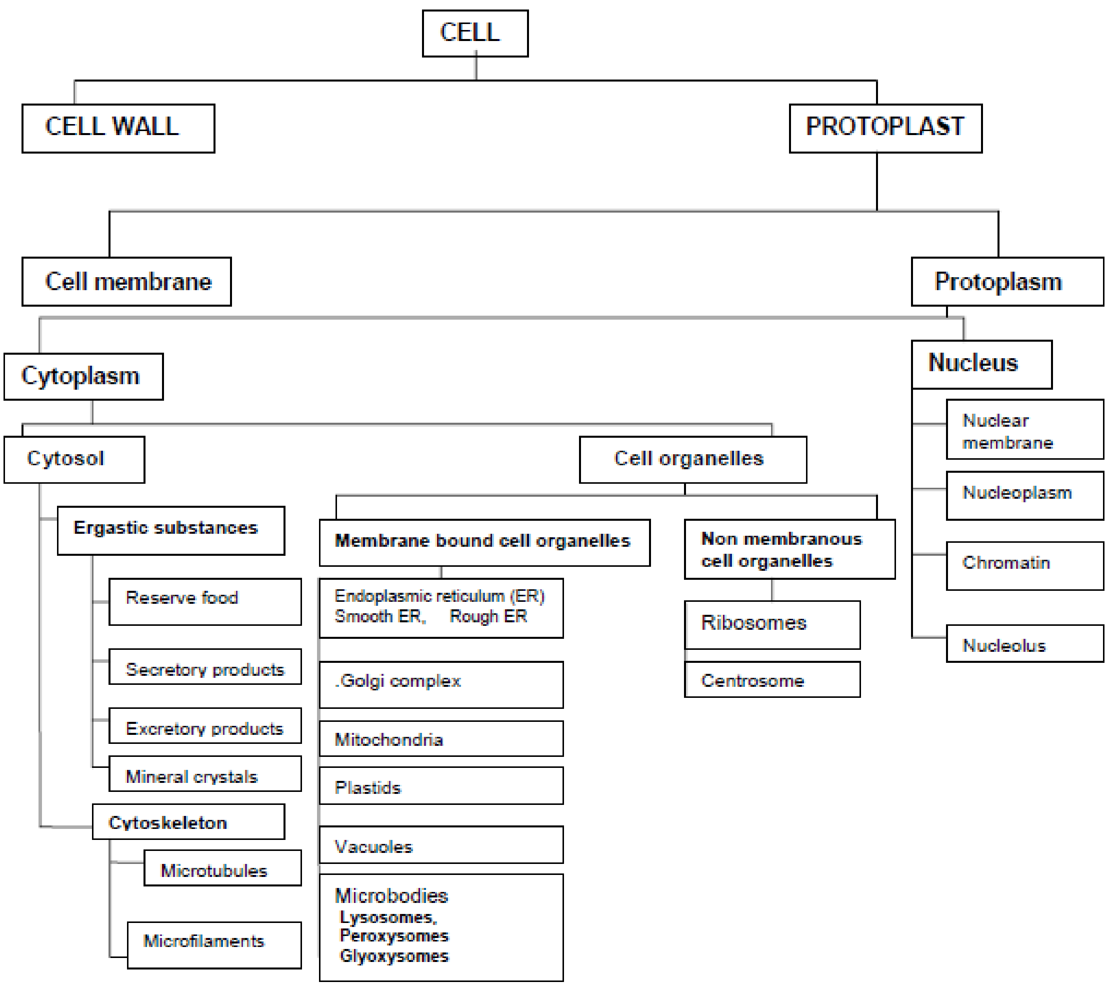
Which Cell Type is Larger?



Comparison of plant and animal cell

Plant cell	Animal cell
Cell wall is present	Cell wall is absent
Centrioles are absent	Centrioles are present
Plastids are present	Plastids are absent
Have large vacuole	May have small vacuoles

Types of cells based on complexity



Cell Wall

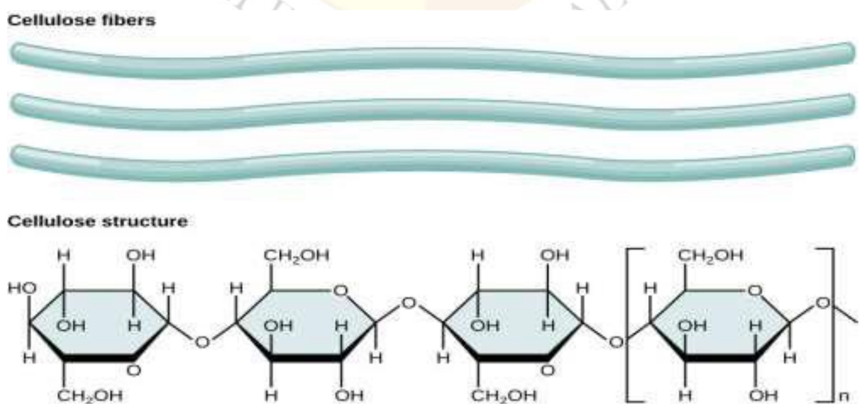
- A plant cell wall first observed and named (simply as a "wall") by Robert Hook in 1665.
- Cell wall is comparatively thick and rigid envelope that surrounds plant cells.
- It was first discovered by Hanstein.
- The cell wall is a protective layer outside the cell membrance that also provides support for the cell's structure.
- A cell wall refers to the rigid and semi permeable protective layer in some types of cells.
- This outer covering is located next to the plasma membrane of the cells of plants, algae, bacteria and fungi.

Chemical Composition of cell wall

- In plants cell wall is made up of cellulose, hemicelluloses and pectins.
- Cellulose microfibrils are embedded in matrix.
- Matrix is the gel like ground substance which consists of water , hemicellulose, pectin, glycoproteins and lipids.
- Hemicellulose contains arabinose, mannose, xylose and galactose.
- Pectin contains Galactose, arabinose ,galactouronic and glucuronic acid.
- The cell wall may have lignin for hardness, silica for stillness and protection, cutin to prevent water loss and suberin for impermeability**.**
- The cell walls of higher plants and some algae are composed principally of cellulose, which is the single most abundant polymer on earth.
- In bacteria, cell wall is composed of peptidoglycan which consists of polymers of NAG (N-acetyl glucosamine) and NAM (N-acetyl muramic acid) cross-linked by short peptides.
- In the cell wall, the pectins form a gel-like network that is interlocked with the crosslinked cellulose microfibrils.

Chemical composition of cell wall

- Cellulose 10-15%
- Hemicellulose 5-15%
- Water 60%
- Protein 1-2%
- Lipids 0.5-3%
- Pectic substances 2-8%



- Lignins are high-molecular-weight, insoluble plant polymers, which have complex and variable structures. They are composed essentially of many methoxylated derivatives of benzene (phenylpropanoid alcohols, also called monolignols), especially coniferyl, sinapyl and coumaryl alcohols.

- Lignification of the cell wall occurs after the laying down of the polysaccharide components of the wall and towards the end of growing period of the cell.
- The purpose of lignifications is to strengthen the cell wall by forming a ramified network throughout the matrix, thus anchoring the cellulose microfibrils more firmly.
- Lignin protects the microfibrils of the wall from chemical, physical and biological attack.
- Plant cell walls particularly of growing cells also contain many proteins which represent 5-10% of the cell wall and glycoproteins, including various enzymes and structural proteins (Rose and Lee, 2010).

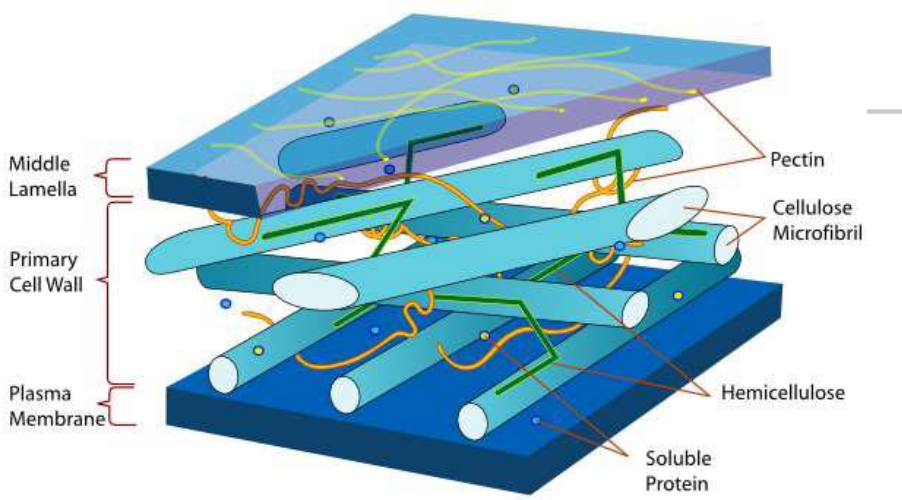
Incrustating substances

Cutin

- The outermost surfaces of the cell walls of epidermal cells are covered with a hydrophobic cuticle.
- The principle function of the cuticle is to reduce the excessive loss and gain of water by the underlying tissue.
- It also protects the tissue from chemical, physical and biological attack to some degree.
- The cutin is the principle polymer of the cuticle. It consists of a complex mixture of hydroxyl fatty acids which are linked together by ester bonds to give a three dimentional network.
- The majority of the fatty acids that are the cutin building units contain 16 to 18 carbon atoms.
- The epicuticular wax is a complex mixture containing mixtures of esters of fatty acids and long chain alcohols.

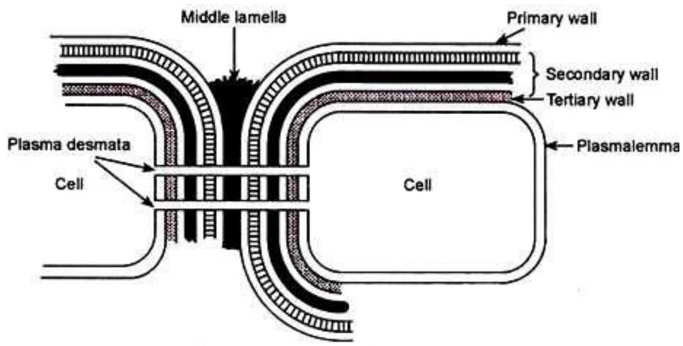
Suberin

- Suberin is complex mixture of fatty acids deposited on cork cells.
- Suberin is a polymeric compound formed from phenylpropanoids, long chain fatty acids and fatty alcohols (C18–C30), as well as hydroxyl fatty acids and dicarboxylic acids (C14–C20).
- It is a waxy substance that is found in the cell wall of higher plants.
- It helps in the control and regulation of movement of solutes through to the xylem.
- Suberin is present in many C4 plants as an impermeable layer between the bundle sheath and mesophyll cells.



Plant cell wall

- In plants cell wall is located outside the cell membrane and provides these cells with structural support and protection, and also acts as a filtering mechanism.
- A major function of the cell wall is to act as a pressure vessel, preventing overexpansion when water enters the cell.
- The structure of cell wall determines the architecture and function of plant cell.
- A typical cell wall is composed of 3-4 layers.
- Middle lamella
- Primary wall
- Secondary wall
- Tertiary wall



Middle lamella

- Middle lamella is the first layer to be formed when a cell divides.
- It is an amorphous intercellular layer between primary walls of adjacent cells.
- It is cementing layer made up of Ca and Mg pectinate/pectate which joins or glues two neighbouring plant cells.
- It is absent on the free surface of plant cells and in plasmadesmata region.
- Middle lamella dissolves in ripe fruits which results in softening.

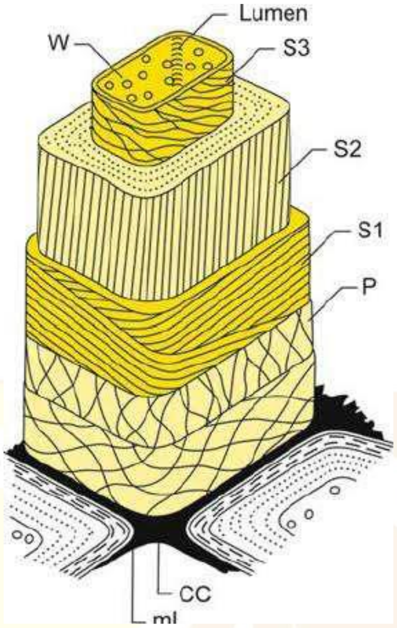
Primary cell wall

- The primary cell wall, generally a thin, flexible and extensible layer formed while the cell is growing.
- It is the first deposition product of protoplasm outside plasma membrane and is present inner to middle lamella.
- Its thickness increases with the growth of the plant cell. It grows by further deposition of wall material into the existing primary wall.

Secondary wall

- Secondary cell wall – it is often deposited on inner side of primary walls after the growth of cell stops (cell matures).
- It is 4-10 μm thick, rigid, non-elastic, permeable and made up of cellulose and lignin deposits.
- Secondary wall deposition is not uniform. At some places secondary wall is not laid down. Such unthickened areas are called pits.
- Pits of two neighbouring cell form pit pair.
- Pits can be of two types – simple or bordered, pit chamber becomes flask shaped due to deposition in the form of border.
- During the development of pits, the secondary cell wall may over arch the pit cavity forming a border, leaving an inner opening called pit-aperture. Such pits with borders are called bordered pits. Two opposite bordered pits are called bordered pit pair.

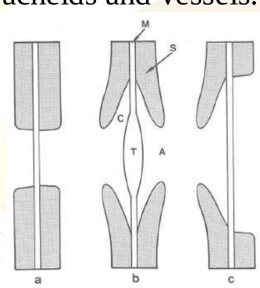
- Bordered pits are present in tracheids of Gymnosperms and vessels of angiosperms.
- Pits which lack the borders are called simple pits. Two opposite simple pits on adjacent cells are called simple pit pair.



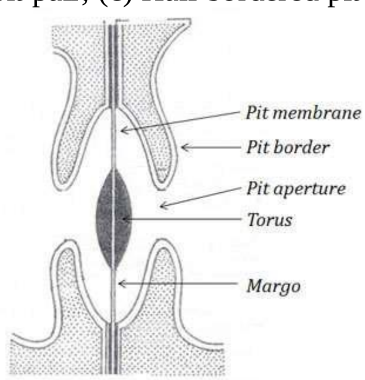
- The secondary cell wall commonly has three layers S_1, S_2, and S_3 e.g , outer layer, the middle layer and the inner layer.

Pits

- In cell wall, perforation are found in the form of simple bordered pits.
- Simple pits are thin walled spots which are formed at certain points where the deposition of the layers of the secondary wall does not take place.
- Bordered pits are the pits, which are partly covered by the innermost layer of the secondary wall as found in dead tracheids and vessels.

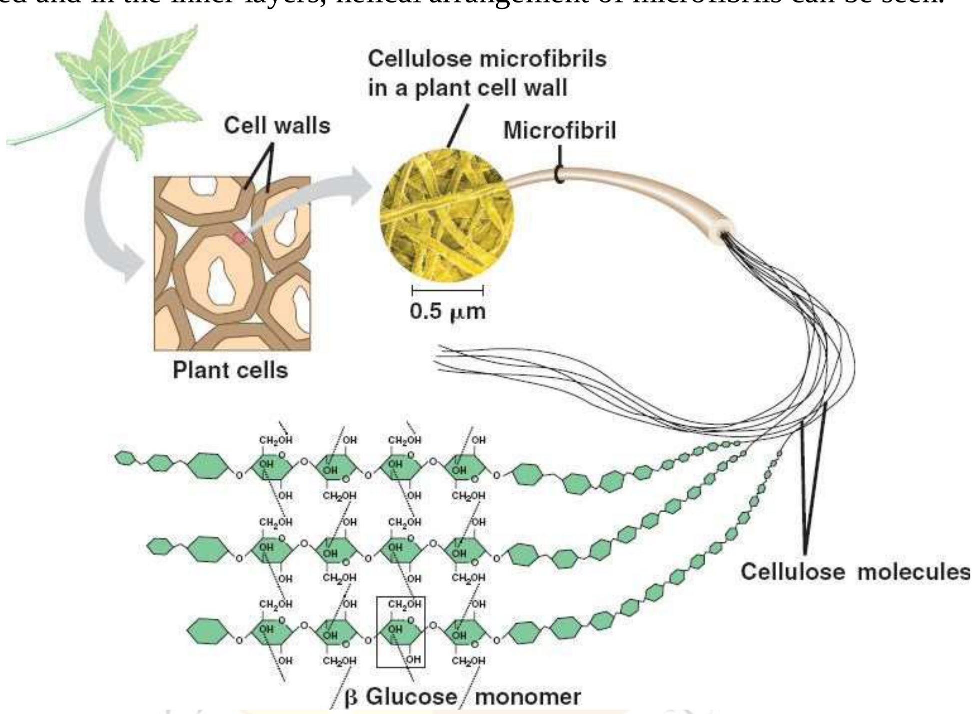


(a) Simple pit pair, (b) Bordered pit pair, (c) Half bordered pit pairs [Source: Siau, 1995]



Ultra-structure of Bordered Pit

- The molecules of the cellulose, however, consist of long chains of about 3000 glucose units (hexose) and in the cell wall these units are associated parallel to one another forming microfibrils.
- Microfibrils are the basic structural units. The cellulosic microfibrils are arranged differently within the primary and secondary cell wall.
- In the primary cell wall, the microfibrils are initially oriented in a transverse direction to the cell axis and during cell enlargement they become reoriented along the longitudinal axis of growth.
- In the secondary cell wall, the microfibrils are arranged in three ways, in the three layers of the secondary wall.
- In the middle layers, a step spiral in addition to concentric rings of spirals can be observed and in the inner layers, helical arrangement of microfibrils can be seen.



Plasmodesmata (Singular Plasmodesma)

- A number of fine cytoplasmic strands (20-40 nm in diameter**)** pass through pits from one cell to other and make connection between the cytoplasm of two cells.
- Endoplasmic reticulum plays a significant role in origin of plasmodesmata.
- Plasmodesmata help in transfer of nutrients, stimuli and other material between adjacent cells and thus produce a protoplasmic continuum called symplast.

Functions of cell wall

- Plant cell walls encase the plant cells and provide many structural and functional roles.
- A major role of the cell wall is to form a framework for the cell to prevent over expansion.
- Cellulose fibers, structural proteins, and other polysaccharides help to maintain the shape and form of the cell.
- The cell wall provides mechanical strength and support. It also controls the direction of cell growth.
- Cell wall protects the cell (protoplast) against loss of water, excessive heat and foreign attacks (plant virus and other pathgens).
- It bestows definite shape ,supporting frame work and rigidity to cell.

- Provides mechanical strength in higher plants having vascular system
- It protects the cell from mechanical injury.
- Cells communicate with one another via plasmodesmata
- It provides a porous medium for circulation (movement) of water, minerals and other nutrients from between adjacent cells.
- Cuticle present on outer surface of epidermal cells (leaves) and suberin present in periderm (bark) prevents water loss.
- The cell wall has an important function in regulating how plant cells achieve their final size and shape and consequently have an essential role in regulating plant growth.
- Some of the proteins of cell wall possess catalytic activity by acting as enzymes to polymerize wall monomers, enzymes that cross-link polymers and enzymes that cleave polymers.

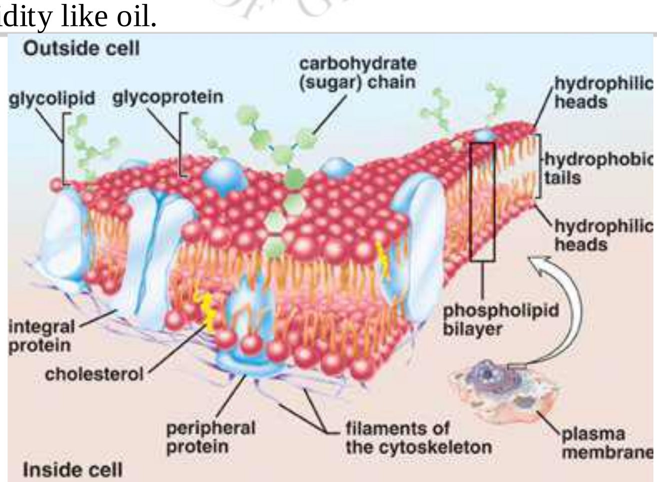
Protoplast: It includes cell membrane and protoplasm.

What is plasma membrane?

- The outer most limit of a cell is composed of living or non-living materials or both it is called as Plasma membrane.
- Plasma membrane also called cytoplasmic membrane,cell membrane or plasmalemma.
- This outer boundary of the cell is also called the plasma membrane. It is composed of four different types of molecules.
- Phospholipids
- Cholesterol
- Proteins
- Carbohydrates
- Many scientists gave various theories and models to explain its structure.
  i. Fluid mosaic model- Singer and Nicolson.(1972)
  ii. Sandwich model -Danielli and Davson.(1930)
  iii. Unit membrane model – Robertson.(1959)

Fluid mosaic model- Singer and Nicolson.(1972)

- This model is proposed by Singer and Nicolson (1972).
- It also shows two layers of lipids and proteins each.
- But according to it the protein layers have two types of molecules. some molecules enter deeply layers and are called intrinsic proteins. They cannot be easily separated.
- Second type of protein molecules which do not enter deeply into the lipid layers but remain attached to their surface only,are called extrinsic proteins. They are easily separable.
- Its viscosity or fluidity like oil.



Functions of Plasma membrane

- Protective barrier
- Regulate transport in & out of cell (selectively permeable)
- Allow cell recognition
- Provide anchoring sites for filaments of cytoskeleton
- Provide a binding site for enzymes
- Contains the cytoplasm

Protoplasm: It is a living substance of the cell that possesses all vital products made up of inorganic and organic molecules. It includes cytoplasm and nucleus.

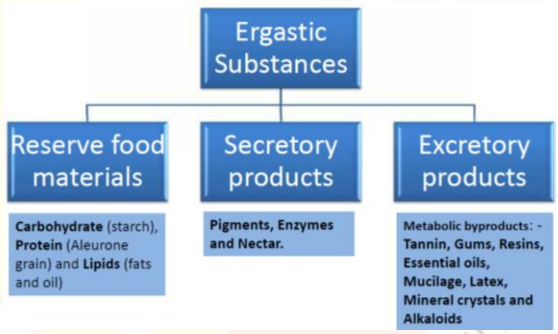
- **Purkinje** (1837) coined the term protoplasm. **Huxley** called protoplasm as **"physical basis of life"**
- **Cytoplasm:** It is the jellylike, semi fluid matrix present between the cell membrane and nuclear membrane. It has various living cell inclusions called **cell organelles** and non living cell inclusions called **ergastic substances and cytoskeletal elements**. The cytoplasm without cell organelles is called **cytosol**.

Non-living inclusions

- Cell contents are divided into two:

  – Living inclusions- all the cell organelles like nucleus, ER, chloroplasts, mitochondria etc.

  – Non-living inclusions- the organic or inorganic substances that are metabolic by-products of the cell- also called non-protoplasmic inclusions or Ergastic substances.



Reserve Food Materials

- These are substances manufactured by the plants from CO2 and water and stored in the plant cells as food materials.
- They breakdown to release energy and are used for various metabolic reactions of the cell. When produced in excess they are stored in the form of reserve food materials. These reserve food materials may be:

  – Starch
  – Proteins
  – Lipids (Oils and Fat)

Starch

• Most of the living cells of stem and root contain starch grains
• It is a long chain polysaccharide formed of glucose units
• Two types of glucose polymers are present
– Alpha amylose
• Unbranched water soluble
– Beta amylose (amylopectin)
• Branched and water insoluble.

- Starch occurs in the form of variously shaped grains.
- Stains bluish black with iodine
- Each starch grain has a central portion called the hilum
- Starchy materials are arranged around the hilum as various striations
- Sometimes they are deposited in the form of concentric rings and hence called concentric starch grains. Eg., Rice, Pea.
- In Potato they are arranged towards one side in the form of eccentric rings and hence called eccentric starch grains
- The starch grain may have only one hilum (Simple starch grain) or may have more than one hilum (Compound starch grain).
- Compound starch grains are formed by fusion of more than two grains.
- Satrch is deposited in the leucoplast (amyloplasts)in cells.

Proteins

- They are complex nitrogenous compounds containing carbon, hydrogen, oxygen and nitrogen sometimes also containing sulphur.
- Present either dissolved in the cell sap or in the form of crystal like bodies called aleurone grains.
- Aleurone grain is a solid ovate or rounded body usually enclosing a crystal like body called crystalloid and a rounded body called globoid.
- Crystalloid is proteinaceous and globoid is a double phosphate of calcium and magnesium.
- Protein plants: Fibrous proteins & Globular protein.

Lipids (Fats and Oils)

- Compounds containing carbon, hydrogen and very less amount of oxygen.
- They are glycerides of fatty acids
- Insoluble in water, soluble in organic solvents.
- Occurs as minute globules in the protoplasm or in organelles called elaioplasts or sphaerosomes.
- Found in fruits and oily seeds like groundnut, coconut, castor seed, sunflower, olive fruits.
- Solid at ordinary temperature- Fats
- Liquids at ordinary temperature- Oils

Secretory Products

- Ergastic substances without any food value.
- Secreted by the protoplasm and helps reactions in cells.
- Sometimes secreted in special sacs or glands.
- Three types:
  – Pigments
  – Enzymes
  – Nectar

Excretory Products

- Also called Metabolic byproducts: Useless to plants and hence excreted through leaves, stem, bark, fruits and seeds.
- Classified into two:

– Nitrogenous waste products
  • Alkaloids
– Non-nitrogenous waste products
  • Tannin

- Gums
- Resins
- Essential oils
- Mucilage
- Latex
- Mineral crystals

Alkaloids

- They are complex compounds of amino acids (amines).
- Many of these alkaloids have medicinal properties which are used to cure diseases in humans.
  - Nicotine- Tobacco
  - Caffeine- Coffee
  - Strychnine- Strychnos

Tannin

- Bitter substances in the cell sap, cell walls and barks of woody plants
- Present in young fruits and quantity decreases with ripening
- Some tannin are used to produce ink
- Some of these are medicinal
- They protect plants from the attack of insects and parasites Gums
- Gums consist of Ca, Mg & K-salts of polyuronides
- Gums have the common property of swelling in water to form either gels or viscous, sticky solutions
- Exuded from stems and twigs of many plants

Eg., Acacia- Gum arabic

Uses

– Stabilizer in emulsion

– It has demulcent (softening) properties and so it is used in cough, diarrhoea and throat medicinal preparations.

– Suspending agent, adhesive and binder in tablet granulation.

Resins

• "Resin" applies to product which is more or less solid, with a complex chemical nature. When heated, they will often soften & melt.

• Produced mainly by coniferous trees.

• Resins are insoluble in water and in petroleum spirit. Will dissolve more or less completely in alcohol, chloroform & ether.

Eg., Turpentine

Essential Oils

• Volatile oils found in special cells or glands

• Responsible for the fragrant odours of flowers, fruits, bark and wood

• Found in the petals of rose, jasmine and some flowers

• Lavender oil from Lavendula, Cinnamon oil from Cinnamomum zeylanicum (Karuva), Peppermint oil from Peppermint

• Used in the preparation of various perfumes and Soaps.

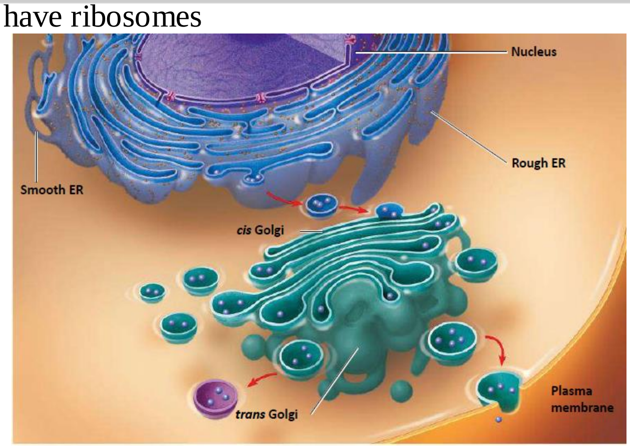
Mineral Crystals

• Mineral crystals are formed by the reaction between acids produced by plants (oxalic acid, Carbonic acid etc.) and the alkaline matters like calcium, magnesium and potash

• Most important crystals in plants

– Calcium oxalate

– Calcium carbonate crystals
– Silica crystals
• They lie loose in the cell or may be aggregated into groups and found hanging from cell walls.
Calcium Oxalate Crystals
• Most common types of crystals
• They are of different forms
– Prisms
– Raphides
– Druses or Sphaeroraphides
Prisms- Crystals of calcium oxalate which are rectangular or pyramidal in shape.
– Found in leaves of lemon, Begonia.
Raphides
– Thin elongated needle like crystals of calcium oxalate- found in raphide sacs.
– Sometimes they are found in bundles.
– Occurs in special mucilage coverings.
– Present in rhizome of Colocasia.
– The raphides at times induce irritation- a means of protection from animals.
– These crystals are destroyed on boiling.
– Stellate crystals found in sclerenchyma of aquatic plants- Idioblasts.
Druses
– Sphaeroidal groups of calcium oxalate crystals.
Calcium carbonate crystals
• Calcium carbonate crystals form grape like clusters hanging from a stalk like projection into the cell cavity from the wall and crystals are deposited on this stalk This is called a cystolith.
• The cystolith is an extension of the cellulosic cell wall with calcium carbonate deposited in the form of granules.
-Found in *Ficus benghalensis.*
-A pair of cystolith is seen together in Momordica – called Double cystolith.
Membrane bound cell organelles present in cytoplasm
1. Endoplasmic reticulum (er):
Discovery: Porter (1945)
Endoplasmic reticulum is a network of membrane bound tubular structures in the cytoplasm. It extends from cell membrane to nuclear membrane. It exists as flattened sacs called **cisternae**, unbranched **tubules** and oval **vesicles.**
There are two types of ER
Rough ER: It has 80s ribosomes on its surface
Smooth ER: It does not have ribosomes



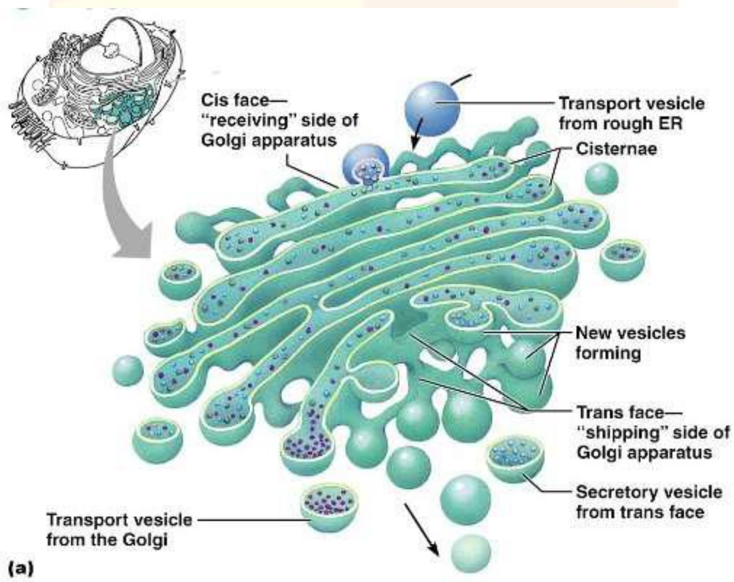
Functions:
• It helps in intracellular transportation
• It provides mechanical support to cytoplasmic matrix
• It helps in the formation of nuclear membrane and Golgi complex
• It helps in detoxification of metabolic wastes
• It is the store house of lipids and carbohydrates

2. Golgi bodies / golgi complex / golgi apparatus / dictyosomes

Discovery: Camillo Golgi (1898), an Italian cytologist discovered Golgi bodies in the nerve cells of barn owl.

Golgi complex has a group of curved, flattened plate like compartments called **cisternae**. They stacked one above the other like pancakes. The cisternae produce a network of **tubules** from the periphery. These tubules end in spherical enzyme filled **vesicles.**

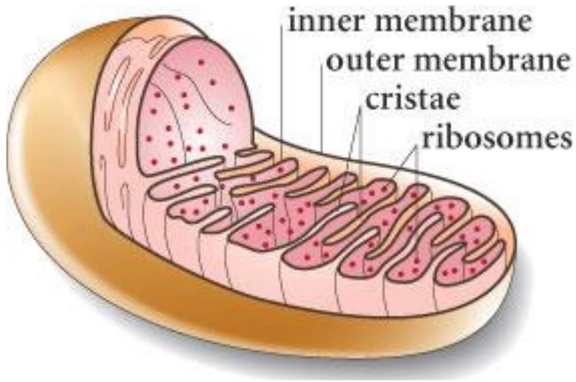
Common name: "Packaging centres" of the cell



Functions:
• They pack enzymes,proteins,carbohydrates etc.in their vesicles, hence called packaging centres
• They produce Lysosomes
• They secrete various enzymes, hormones and cell wall material
• They help in phragmoplast formation

3. Mitochondria / chondriosome

Discovery – Kolliker (1880)- discovered in the muscle cells of insects, **Altman** called them as **Bioplasts, Benda** (1897) coined the term **Mitochondria**



Mitochondrion is a spherical or rod shaped cell organelle. It has two membranes. The outer membrane is smooth. The inner membrane produces finger like infoldings called **cristae.** The inner membrane has stalked particles called **Racker's particles** or **F0 – F1 particles** or **Claude's particle** or **ATP synthase complex.** The mitochondrial cavity is filled with a homogenous granular **mitochondrial matrix.** The matrix has circular mitochondrial DNA, RNA, 70s ribosomes, proteins, enzymes and lipids.

Common name: Power houses of the cell / Storage batteries of the cell

Functions:

Mitochondria synthesise and store the energy rich molecules ATP (Adenosine triphosphate) during aerobic respiration. So, they are called "**Power houses of the cell**".

4. Plastids:

Discovery: They were first observed by **AFW Schimper (1885)**

Plastids are present in plant cells and euglenoids.

Plastids are classified into three types based on the type of pigments.

1. **Chromoplasts:** These are different coloured plastids containing carotenoids. These are present in fruits, flower and leaves.

2. **Leucoplasts:** These are colourless plastids which store food materials.

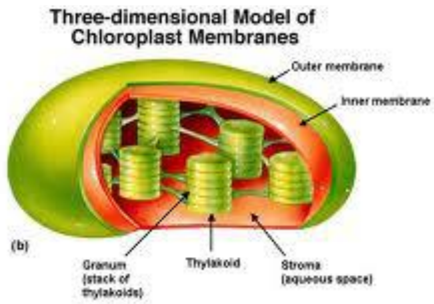
Ex: Amyloplasts: Store starch

Aleuronoplasts: Store proteins

Elaeioplasts: Store lipids

3. **Cholorplasts:** These are green coloured plastids containing chlorophylls and carotenoids (carotenes & xanthophylls). Chloroplast is a double membranous cell organelle. The matrix is called **stroma.** The stroma has many membranous sacs called **Thylakoids**. They arrange one above the other like a pile of coins to form **Granum**. The grana are interconnected by **Fret membranes** or **Stroma lamellae** or **Intergranal membranes** or **Stromal thylakoids**. These membranous structures have photosynthetic pigments like chlorophylls, carotenes and xanthophylls (carotenols).They have four major complexes namely, photosystem I (PSI), photosystem II (PSII), cytochrome b6 – f complex and ATP synthase. The **stroma** has a circular chloroplast DNA, RNA, 70s ribosomes, enzymes and co enzymes. Chloroplasts help in **photosynthesis.** (Synthesis of food molecules by utilizing CO2, water and solar energy)

Common name: Kitchen of the cell



Mitochondria and plastids have their own DNA called organelle DNA and 70s ribosomes. So, they are able to prepare their own proteins. Hence they are considered as 'semiautonomous cell organelles'.

5. Vacuoles: Vacuoles are single membrane bound sac like vesicles present in cytoplasm. The plant cells have large vacuole and animal cells may have smaller vacuoles. The membrane of the vacuole is called **tonoplast**. Tonoplast is a semi permeable membrane. The vacuole is filled with a watery fluid called **cell sap.** The cell sap has dissolved salts, sugars, organic acids, pigments and enzymes. There are different types of vacuoles. They are

• **Contractile vacuole:** These are present in fresh water protozoans and some algae. They take part in digestion, excretion and **osmoregulation** (maintenance of water balance)

• **Food vacuoles:** These are the vacuoles containing food particles. These are produced due to phagocytosis of cell.

• **Gas vacuoles:** These vacuoles contain gases and help in **buoyancy**.

• **Storage vacuoles:** These function like reservoirs and help in turgidity – flaccidity changes in plant cells

6. Microbodies: These are small, spherical, single membrane bound structures present in cytoplasm. The different types of microbodies are

a) **Lysosomes**: **Discovery:** Lysosomes are first reported by Belgian scientist **Christian de Duve** (1995) in rat liver cells. **Nivicott** (1950) coined Lysosomes.

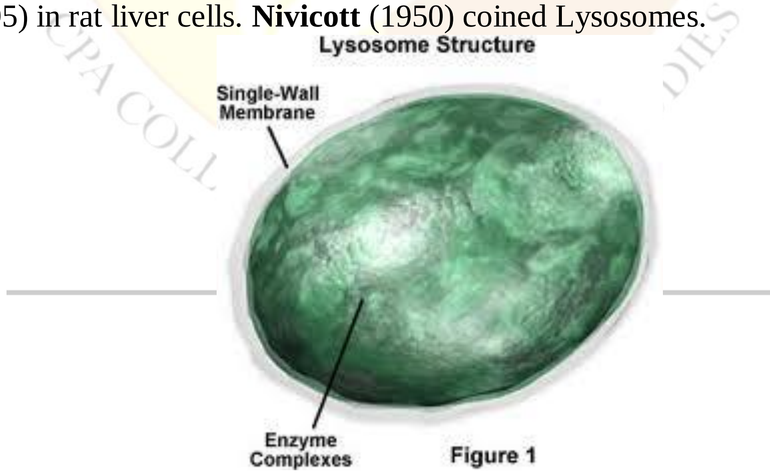


Figure 1

These are small single membrane bound vesicles filled with **hydrolytic enzymes**. Lysosomes are produced from Golgi complex. **The Lysosomal membrane is lipoproteinic. It has stabilizers like cholesterol, cortisone, cortisol, vitamin E which give stability to the membrane. So, the enzymes do not digest the membrane**.

The types of Lysosomes are

• **Primary Lysosomes**: Newly produced Lysosomes from golgibodies

• **Secondary Lysosomes (Phagolysosome)**: These are formed by the union of phagosome and primary lysosome. It is also called **digestive vacuole**

• **Residual Lysosomes:** These are secondary Lysosomes left with undigested material which is thrown out by exocytosis

• **Autolysosomes (Autophagic lysosome)**: These are formed by the union of primary lysosome and worn out cell organelles

Common name: Suicidal bags of cell / Time bombs of the cell / Recycling centers

Functions:

• They are concerned with intracellular digestion

• They contribute to ageing process

• They destroy old and non functional cells which bear them (Autolysis). So they are called **suicidal bags**

• They break worn-out cells, damaged cells and cell organelles to component molecules for building new cell organelles. So they are called " **Recycling centers"** The Lysosomal membrane is lipoproteinic. It has stabilizers like cholesterol, cortisone, cortisol, vitamin E which give stability to the membrane. So, the enzymes do not digest the membrane.

b) Peroxysomes: These oxidize substrates producing hydrogen peroxide and involved in photorespiration

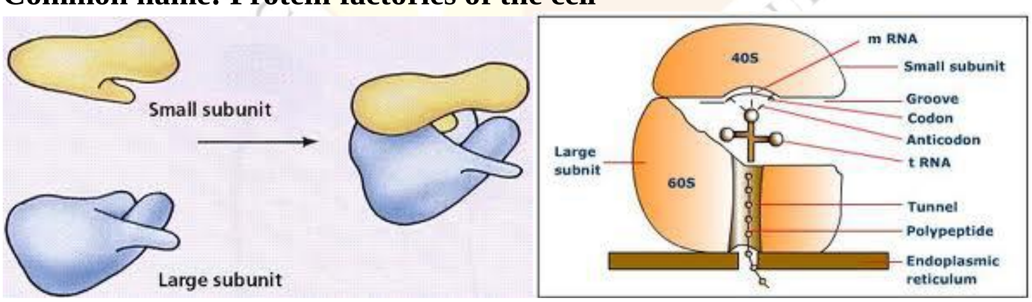
c) Glyoxysomes: These store fat and convert it into carbohydrates.

B. Non membranous cell organelles present in the cytoplasm

These organelles do not have any membranous covering. They are **Ribosomes** and **Centrosome.**

1. **Ribosomes: Discovery: K R Porter (1945**) - observed in animal cells, **Robinson and Brown (1953**) observed in plant cells, **George Plate (1953**) - coined the term Ribosome These are granular, nonmembranous sub spherical structures present in the cytoplasm, mitochondria and chloroplast. They are also found attached to Rough ER and nuclear membrane. The ribosomes are composed of r-RNA and proteins. Prokaryotes have 70s (50s + 30s) ribosomes in cytoplasm. Eukaryotes have 80s (60s+40s) ribosomes in cytoplasm and 70s (50s +30s) ribosomes in mitochondria and plastids.

   Common name: Protein factories of the cell



Function: These are the sites of polypeptide or protein synthesis

2. Centrosome: **Discovery: Van Benden (1880)**

Centrosome is found in animal cells and in some motile algae. It is absent in plant cells. It is present near the nucleus.Centrosome has two cylindrical structures called **centrioles** surrounded by a less denser cytosol called **centrosphere**. The centrioles are arranged at right angles to one another. Each centriole is made up of a whorl of nine triplets of microtubules. These microtubules run parallel to one another. The adjacent microtubules are connected by proteinaceous strands.

Functions:
• They form asters and organize the formation of spindle fibres during cell division.
• They are involved in the formation of cilia, flagella and axial filament in sperms.

Nucleus

- The nucleus was the first organelle to be discovered and named-Robert Brown (1833)
- Houses the cell genome- serves as a repository of genetic information-
- 'MASTER CONTROL CENTER'

Morphology-Number:

- 1. Mononucleate cells.
- 2. Binucleate cells. e.g. Paramecium, hepatocytes, chondrocytes.
- 3. Polynucleate cells: (3-100)

Shapes:

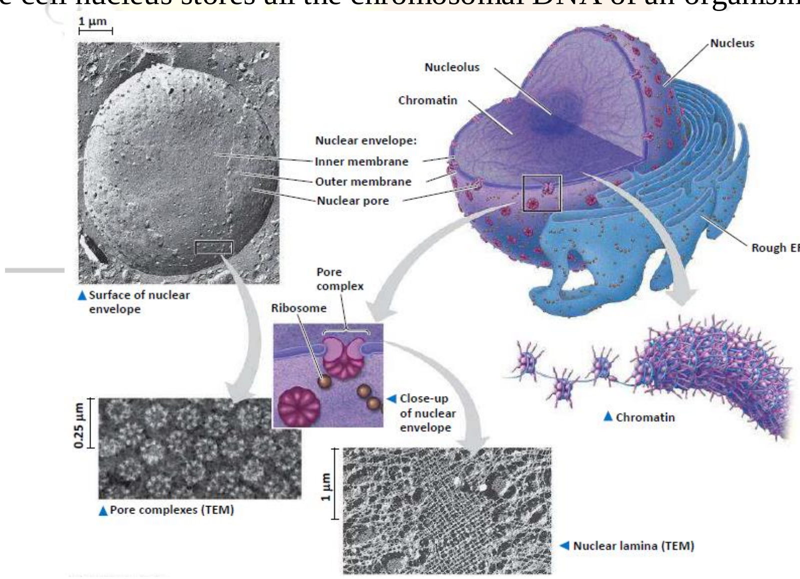
- Spheroid, Cuboid, Isodiametric, ellipsoid
- Leukocytes- irregular.

Size:

- 10% of cell volume. - Size varies from 3µm to 25 µm.

Functions of Nucleus

- It controls the hereditary characteristics of an organism.
- Responsible for the protein synthesis, cell division, growth, and differentiation.
- Storage of hereditary material, the genes in the form of long and thin DNA (deoxyribonucleic acid) strands, referred to as chromatins.
- Storage of proteins and RNA (ribonucleic acid) in the nucleolus.
- Site for transcription in which messenger RNA (mRNA) are produced for the protein synthesis.
- During the cell division, chromatin is arranged into chromosomes in the nucleus.
- Production of ribosomes (protein factories) in the nucleolus.
- Selective transportation of regulatory factors and energy molecules through nuclear pores.
- Overall, the cell nucleus stores all the chromosomal DNA of an organism.



Structural components of nuclear envelope

- Encloses the nucleus-Provides structural framework

  1. Nuclear membranes (Perinuclear space; 10-50 nm),

2. Nuclear pore complexes and
3. Nuclear lamina

The nuclear membrane is a double membrane;

- Each membrane consists of a lipid bilayer.
- Acts as a barrier that keeps ions, solutes, and macromolecules from passing freely between the nucleus and cytoplasm.
- The two membranes are fused at sites forming circular pores that contain complex assemblies of proteins (Nuclear protein complexes).
- The outer membrane is generally studded with ribosomes and is continuous with the membrane of the rough endoplasmic reticulum.
- The inner surface of the nuclear envelope is bound by integral membrane proteins to a thin filamentous meshwork, called the nuclear lamina.
- The nuclear lamina provides mechanical support to the nuclear envelope.
- Serves as a site of attachment for chromatin fibers at the nuclear periphery.
- The filaments of the nuclear lamina are 10 nm (app.) in diameter and composed of lamins.
- Responsible for the protein synthesis, cell division, growth, and differentiation.
- Storage of hereditary material, the genes in the form of long and thin DNA.

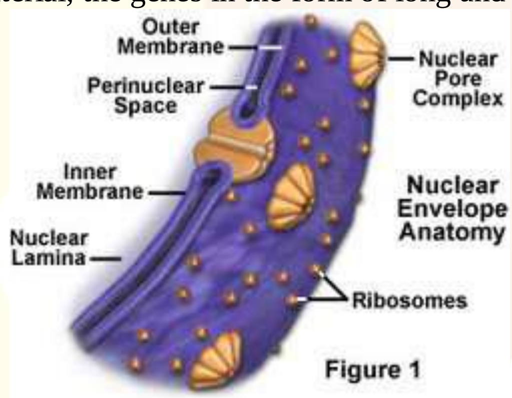


Figure 1

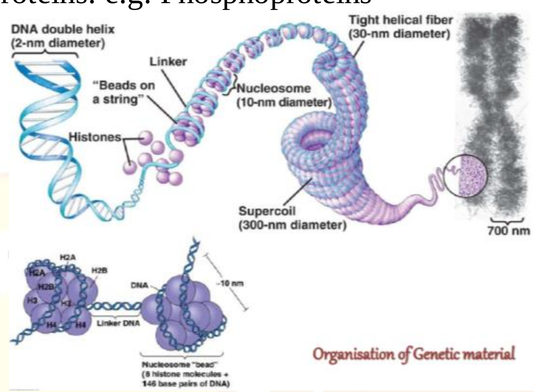
Nucleolus

- It is a large aggregate of macromolecules including the precursor rRNA, mature rRNA, rRNA processing enzymes, snoRNPs, ribosomal protein subunits and
- Mammalian cells 1-5 nucleoli each 0.5-5 um in diameter
- Not membrane bound
- Morphologically, nucleoli consist of 3 different regions;
  a) The fibrillar center (Transcription of the rDNA)
  b) Dense fibrillar component (rRNA processing) and
  c) Granular component (Ribosome assembly)
- Site for rRNA transcription and processing
- No. of nucleoli in any cell is usually reflective of its function
- (Protein synthesis-Ribosomal subunit construction)

Nucleoplasm

- Transparent, granular, dense, ground substance of nucleus.
- Also called nuclear sap, nucleoplasm, karyolymph
- Enclosed by the nuclear envelope.
- Highly gelatinous sticky liquid which supports the chromatin and nucleolus.
- Maintains the shape and structure of the nucleus.
- Contains enzymes required by DNA replication and transcription.

- Posttranscriptional modifications of the mRNA, and ribosome biogenesis also occur in the nucleoplasm
- 32% (6297 proteins) of all human proteins have been experimentally detected in the nucleoplasm by the Human Protein Atlas Composed of
- Nucleic Acids: DNA, RNA.
- Proteins : Complex proteins,
- Basic Proteins: Nucleoprotamines- M.W. = 4kDa
- Nucleohistones- M.W.= 10 to 18 kDa.
- Non-Histones/ Acidic Proteins: e.g. Phosphoproteins



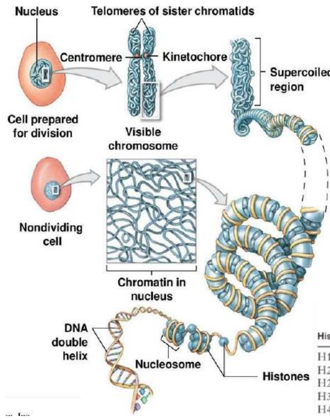
Organisation of Genetic material

Chromosome: The nucleus of a normal or non dividing cell has a loosened indistinct network of nucleoprotein fibers called **chromatin** (coined by **Flemming**). During cell division the chromatin condenses to form distinctly visible chromosomes.

Discovery: The term chromosome (chroma – colour, soma – body) was coined by **Waldeyer (1888),** Discovered by **Holf Meister (1848)** observed in pollen mother cells of *Tradescantia*. **T H Morgan** discovered the role of chromosome during transmission of characters and called them as **'vehicles of heredity'**. A metaphase chromosome has two similar darkly stainable parallel strands called **chromatids** held at a point called **centromere.** Centromere is a less stained primary constricted region having **kinetochores & microtubules**. Each chromatid is made up of a highly coiled thread like structure called **chromonema** or chromatin fibre made up of **DNA and Histones**. The coiling of the cells having nucleus are called **Nucleated or Eunucleated cells**.

- The cells which loose nucleus at maturity are called **Enucleated cells**. Ex: Mammalian RBC, Sieve tube members of angiosperms.
- The cells having incipient nucleus are called **prokaryotic cells** Ex:Bacteria, Nostoc.
- The cells having well defined nucleus are called **Eukaryotic cells** Ex:Higher plant & animal cell Nucleolus is called **ribosome factory** because it is involved in the synthesis of necessary molecules required for the production of ribosomes – discovered by **Fontana**. Chromonema results in bead like structures called **chromomeres**. At certain regions of chromosome is a tightly coiled, more stainable less active chromonema called **heterochromatin** and the loosely coiled, less stainable more active region called **euchromatin.** Chromosomes are classified into different types based on the position of centromere.They are Telocentric, acrocentric, submetacentric, metacentric chromosomes.

Functions: Chromosomes are the vehicles of heredity.



DNA exists in Chromatin form in the nucleus. The chromatin condenses to form Chromosomes during cell division.

Five classes of histones.

Histone	Number of residues	Mass (kDa)	%Arg	%Lys
H1	215	23.0	1	29
H2A	129	14.0	9	11
H2B	125	13.8	6	16
H3	135	15.3	13	10
H4	102	11.3	14	11

Module II

Special type of chromosomes

Satellite chromosome

- Satellite Chromosome is the chromosome which has a bulge on the telomeric end & contains SAT DNA.
- Also referred to as SAT Chromosome, it plays a vital role in the formation of the nucleolous after division is completed.
- It shows repetitive sequences of genes.
- Besides centromere, secondary constriction can also be observed in some chromosomes, which if present in the distal region of the arm, would pinch off a small fragment called Satellite.
- Satellite remains attached to the rest of the body of chromosomes by a thread of chromatin.
- Secondary constrictions are always constant in their positions & can be used as markers.
- Chromosomes having a satellite are marker chromosomes & are called SAT chromosomes.

Polyteny

- The most thoroughly-studied examples of polyteny are the giant chromosomes found in certain cells of dipteran flies.
- Polytene chromosomes are found in salivary gland cells of *Drosophila melanogaster*.
- These are so large that they can be seen during interphase; even with a low-power light microscope.
- Polytene chromosomes are bundles of unseparated chromonemata occurring especially in the salivary glands of some insects; called also Giant Chromosomes.
- Polytene chromosomes - 1st observed in larval salivary glands of Chironomus midges by Balbiani (1881).

Lampbrush chromosomes

- Lampbrush chromosomes are giant chromosomes arranged like a “Victorian” brush, used to clean chimney’s of lamps.
- A Lampbrush chromosome is a large chromosome that is found especially in the oocytes (immature eggs) of amphibians, birds and other animals.
- Lampbrush chromosomes occur during the diplotene stage of meiosis I.
- Lampbrush chromosomes are meiotic bivalents formed of 2 sister chromatids, joined at chiasmata.
- Each halve-bivalent is represented by two long strands that form many brushlike loops along the main axis of the chromosome.

- The outgrowths make DNA available for transcription during the maturation of the egg.
- There is a little gene expression at meiosis, so it is not so easy to identify the activities of individual genes.

Cell Cycle – Progression & Regulation

- The cell cycle, or cell-division cycle, is the series of events that take place in a eukaryotic cell leading to its replication.
- Cell cycle is divided into two : interphase — during which the cell grows, accumulating nutrients needed for mitosis and duplicating its DNA — & the mitotic (M) phase, during which the cell splits itself into two distinct cells, called "daughter cells".
- Cell-division cycle is a vital process by which a single-celled fertilized egg develops into a mature organism, as well as the process by which hair, skin, blood cells & internal organs are renewed.
- Cell cycle consists of G1 phase, S phase, G2 phase (together known as interphase) and M phase.
- M phase is itself composed of two tightly coupled processes: mitosis, in which the cell's chromosomes are divided between the two daughter cells, and cytokinesis, in which the cell's cytoplasm divides forming distinct cells.
- Activation of each phase is dependent on the proper progression & completion of previous one.
- Cells that have temporarily or reversibly stopped dividing are said to have entered a state of quiescence called G0 phase.

M phase

- The relatively brief M phase consists of nuclear division (mitosis) & cytoplasmic division/cytokinesis.
- In plants and algae, cytokinesis is accompanied by the formation of a new cell wall.
- The largest of all these processes is (interphase).
- Interphase
- After M phase, the daughter cells each begin interphase, the various stages of which are not usually morphologically distinguishable.
- Each phase of the cell cycle has a distinct set of specialized biochemical processes that prepare the cell for initiation of cell division.

G1 phase

- The first phase within interphase, from the end of the previous M phase till the beginning of DNA synthesis is called G1 (G indicating gap or growth).
- During this phase the biosynthetic activities of the cell, which had been considerably slowed down during M phase, resume at a high rate.
- This phase is marked by synthesis of various enzymes that are required in S phase, mainly those needed for DNA replication.
- Duration of G1 is highly variable, even among different cells of the same species.

S phase

- S phase starts when DNA synthesis commences.
- When it is complete, all of the chromosomes have been replicated, i.e., each chromosome has two (sister) chromatids.
- Thus, during this phase, the amount of DNA in the cell has effectively doubled, though the ploidy of the cell remains the same.
- Rates of RNA transcription and protein synthesis are very low during this phase.
- An exception to this is histone production, most of which occurs during the S phase.

- The duration of S phase is relatively constant among cells of the same species.

G2 phase

- The cell then enters the G2 phase, which lasts until the cell enters mitosis.
- Again, significant protein synthesis occurs during this phase, mainly involving the production of microtubules, which are required during the process of mitosis.
- Inhibition of protein synthesis during G2 phase prevents the cell from undergoing mitosis.

G0 phase

- The term "post-mitotic" is sometimes used to refer to both quiescent and senescent cells.
- Nonproliferative cells in multicellular eukaryotes generally enter the quiescent G0 state from G1 and may remain quiescent for long periods of time, possibly indefinitely. This is very common for cells that are fully differentiated.
- Cellular senescence is a state that occurs in response to DNA damage or degradation that would make a cell's progeny nonviable.
- It is often a biochemical alternative to the self-destruction of such a damaged cell by apoptosis.

Regulation of cell cycle

- Regulation of the cell cycle involves steps crucial to the cell, including detecting and repairing genetic damage and provision of various checks to prevent uncontrolled cell division.
- The molecular events that control the cell cycle are ordered and directional; that is, each process occurs in a sequential fashion and it is impossible to "reverse" the cycle.

Role of cyclins and cdks

- Two key classes of regulatory molecules, cyclins and cyclin-dependent kinases (CDKs), determine a cell's progress through the cell cycle.
- Leland H. Hartwell, R. Timothy Hunt, and Paul M. Nurse won the 2001 Nobel Prize in Physiology/ Medicine for their discovery of these central molecules.
- Many of the genes encoding cyclins and CDKs are conserved among all eukaryotes, but in general more complex organisms have more elaborate cell cycle control systems.
- Many of the relevant genes were first identified in yeast, especially *Saccharomyces cerevisiae*.
- Cyclins form the regulatory subunits and CDKs the catalytic subunits of an activated heterodimer.
- Cyclins have no catalytic activity and CDKs are inactive in the absence of a partner cyclin.
- When activated by a bound cyclin, CDKs perform phosphorylation that activates or inactivates target proteins to enter into the next phase of cell cycle.
- Different cyclin-CDK combinations determine the functioning of the cell cycle.

Interphase

- The mitotic phase (M) is a relatively short period of the cell cycle. It alternates with the much longer *interphase*, where the cell prepares itself for cell division. Interphase is divided into three phases, G1 (first gap), S (synthesis), and G2 (second gap). During all three phases, the cell grows by producing proteins and cytoplasmic organelles. However, chromosomes are replicated only during the S phase. Thus, a cell grows (G1), continues to grow as it duplicates its chromosomes (S), grows more and prepares for mitosis (G2), & divides (M).

Prophase

- Normally, the genetic material in the nucleus is in a loosely bundled coil called chromatin.
- At the onset of prophase, chromatin condenses together into a highly ordered structure called a chromosome.
- Since the genetic material has already been duplicated earlier in S phase, the replicated chromosomes have two sister chromatids, bound together at the centromere by the cohesion complex.

Prometaphase

- The nuclear membrane has degraded, and microtubules have invaded the nuclear space.
- These microtubules can attach to kinetochores or they can interact with opposing microtubules.
- This is called open mitosis, and it occurs in most multicellular organisms.
- Each chromosome forms two kinetochores at the centromere, one attached at each chromatid.

Metaphase

- As microtubules find and attach to kinetochores in prometaphase, the centromeres of the chromosomes convene along the metaphase plate or equatorial plane, an imaginary line that is equidistant from the two poles.
- This even alignment is due to the counterbalance of the pulling powers generated by the opposing kinetochores.
- In certain types of cells, chromosomes do not line up at the metaphase plate and instead move back and forth between the poles randomly, only roughly lining up along the midline. Metaphase comes from the Greek μετα meaning "after."
- Because proper chromosome separation requires that every kinetochore be attached to a bundle of microtubules (spindle fibers) , it is thought that unattached kinetochores generate a signal to prevent premature progression to anaphase without all chromosomes being aligned.

Anaphase

- When every kinetochore is attached to a cluster of microtubules and the chromosomes have lined up along the metaphase plate, the cell proceeds to anaphase.
- Two events then occur; First, the proteins that bind sister chromatids together are cleaved, allowing them to separate.
- These sister chromatids turned sister chromosomes are pulled apart by shortening kinetochore microtubules and move toward the respective poles to which they are attached.
- Next, the non-kinetochore microtubules elongate, pushing the sets of chromosomes apart to opposite ends of the cell. Early anaphase is usually defined as the separation of the sister chromatids, while late anaphase involves the elongation of the microtubules and the microtubules being pulled farther apart.
- At the end of anaphase, the cell has succeeded in separating identical copies of the genetic material into two distinct populations.

Telophase

- Telophase (from the Greek *τελος* meaning "end") is a reversal of prophase and prometaphase events. It "cleans up" the after effects of mitosis.
- At telophase, the non-kinetochore microtubules continue to lengthen, elongating the cell even more. Corresponding sister chromosomes attach at opposite ends of the cell.

- A new nuclear envelope, using fragments of the parent cell's nuclear membrane, forms around each set of separated sister chromosomes.
- Both sets of chromosomes, now surrounded by new nuclei, unfold back into chromatin.
- Mitosis is complete, but cell division is not yet complete.

Cytokinesis

- Cytokinesis is often mistakenly thought to be the final part of telophase, however cytokinesis is a separate process that begins at the same time as telophase.
- Cytokinesis is technically not even a phase of mitosis, but rather a separate process, necessary for completing cell division.
- In both animal and plant cells, cell division is also driven by vesicles derived from the Golgi apparatus, which move along microtubules to the middle of the cell.

Meiosis – Chromosome Mechanisms and Events

- Meiosis (pronounced mi-o-sis / me-o-sis) is the process by which one diploid eukaryotic cell divides to generate 4 haploid cells, called gametes.
- The word "meiosis" comes from the Greek meioun, meaning "to make smaller," since it results in a reduction in chromosome number in gamete cell.
- Meiosis is essential for sexual reproduction and therefore occurs in all eukaryotes (including single-celled organisms) that reproduce sexually.
- A few eukaryotes, notably the Bdelloid rotifers, have lost the ability to carry out meiosis and have acquired the ability to reproduce by parthenogenesis.
- Meiosis does not occur in archaea or bacteria, which reproduce via asexual processes such as mitosis or binary fission.
- During meiosis, the genome of a diploid germ cell, which is composed of long segments of DNA packaged into chromosomes, undergoes DNA replication followed by two rounds of division, resulting in haploid cells called gametes.
- Each gamete contains one complete set of chromosomes, or half of the genetic content of the original cell.

Meiotic cell cycle

- Interphase is divided into three phases:
- Growth 1 (G1) phase: Immediately follows cytokinesis. This is a very active period, where the cell synthesizes its vast array of proteins, including the enzymes and structural proteins.
- Synthesis (S) phase: Genetic material is replicated: chromosomes duplicates.
- Cell is still diploid, however, because it still contains the same number of centromeres.
- However, the identical sister chromatids are in the chromatin form because spiralisation and condensation into denser chromosomes have not taken place yet.
- It will take place in prophase I in meiosis.
- Growth 2 (G2) phase: absent in Meiotic cell cycle.

M-PHASE

- Interphase is immediately followed by meiosis I and meiosis II.
- Meiosis encompasses the interphase (G1, S, G2), meiosis I (prophase I, metaphase I, anaphase I, telophase I), and meiosis II (prophase II, metaphase II, anaphase II, telophase II)

MEIOSIS I

- It consists of segregating the homologous chromosomes from each other, then dividing the diploid cell into two haploid cells each containing one of the segregates.

Prophase I

- DNA replication precedes the start of meiosis I.
- During prophase I, homologous chromosomes pair and form synapses, a step unique to meiosis.
- The paired chromosomes are called bivalents, and the formation of chiasmata caused by genetic recombination becomes apparent.

Leptotene

- The *leptotene* stage, also known as *leptonema*, arise from Greek words meaning "thin threads.“
- During this stage, individual chromosomes begin to condense into long strands within the nucleus.
- However the two sister chromatids are still so tightly bound that they are indistinguishable from one another.

Zygotene

- The *zygotene* stage, also known as *zygonema*, from Greek words meaning "paired threads," occurs as the chromosomes approximately line up with each other into homologous chromosomes.
- The combined homologous chromosomes are said to be *bivalent*.
- They may also be referred to as a *tetrad*, a reference to the four sister chromatids.
- Two chromatids become "zipped“, forming the synaptonemal complex, in a process known as synapsis & forms a synapton.

Pachytene

- The *pachytene* stage, also known as *pachynema*, from Greek words meaning "thick threads," contains the following chromosomal crossover.
- Nonsister chromatids of homologous chromosomes randomly exchange segments of genetic information over regions of homology.
- Sex chromosomes, however, are not identical, and only exchange information over a small region of homology.
- Exchange takes place at sites where *recombination nodules* have formed.
- The exchange of information between the non-sister chromatids results in a recombination of information.
- Each chromosome has the complete set of information it had before, and there are no gaps formed as a result of the process.

Diplotene

- During the *diplotene* stage, also known as *diplonema*, from Greek words meaning "two threads," the synaptonemal complex degrades and homologous chromosomes separate from one another a little.
- Chromosomes uncoil a bit, allowing some transcription of DNA.
- However, homologous chromosomes of each bivalent remain tightly bound at chiasmata, where crossing over had occurred.

Diakinesis

- Chromosomes condense further during the *diakinesis* stage, from Greek words meaning "moving through.".
- This is the first point in meiosis where the four parts of the tetrads are actually visible.

- Sites of crossing over entangle together, effectively overlapping, making chiasmata clearly visible.
- Other than this observation, the rest of the stage closely resembles prometaphase of mitosis.
- The nucleoli disappear, the nuclear membrane disintegrates into vesicles, and the meiotic spindle begins to form.

Metaphase I

- Homologous pairs move together along the phase plate: as kinetochore microtubules from both poles attach to their respective kinetochores, the homologous chromosomes align along an equatorial plane that bisects the spindle, due to continuous counterbalancing forces exerted on the bivalents by the microtubules emanating from the two kinetochores.
- The physical basis of the independent assortment of chromosomes is the random orientation of each bivalent along the metaphase plate.

Anaphase I

- Kinetochore microtubules shorten, severing the recombination nodules and pulling homologous chromosomes apart.
- Since each chromosome only has one kinetochore, whole chromosomes are pulled toward opposing poles, forming two haploid sets.
- Each chromosome still contains a pair of sister chromatids.
- Nonkinetochore microtubules lengthen, pushing the centrioles further apart.
- The cell elongates in preparation for division down the middle.

Telophase I

- The first meiotic division effectively ends when the centromeres arrive at the poles.
- Each daughter cell now has half the number of chromosomes but each chromosome consists of a pair of chromatids.
- The microtubules that make up the spindle network disappear, and a new nuclear membrane surrounds each haploid set.
- The chromosomes uncoil back into chromatin.

Cytokinesis

- The pinching of the cell membrane in animal cells or formation of the cell wall in plant cells, occurs, completing the creation of two daughter cells.
- Cells enter a period of rest known as interkinesis or interphase II.

Interphase II

- During the short interphase II, no DNA replication occurs. Note that many plants skip telophase I and interphase II, going immediately into prophase II.

Meiosis II

- Meiosis II consists of decoupling each chromosome's sister chromatids, segregating the DNA into two sets of strands (each set containing one of each homologue).
- Meiosis II also involves dividing both haploid, duplicated cells to produce four haploid, unduplicated cells.
- Meiosis II is the second part of the meiotic process.
- The process is similar to mitosis and meiosis I.

Prophase II

- It takes an inversely proportional time compared to telophase I.
- In this prophase we see the disappearance of the nucleoli and the nuclear envelope again as well as the shortening and thickening of the chromatids.

- Centrioles move to the polar regions and arrange spindle fibers for the second meiotic division.
- The new equatorial plate is rotated by 90 degrees when compared to meiosis I, perpendicular to the previous plate.

Metaphase II

- In this stage, the centromeres contain two kinetochores, that attach to spindle fibers from the centrosomes/MTOC at each pole.

Anaphase II

- The centromeres are cleaved, allowing microtubules attached to the kinetochores to pull the sister chromatids apart.
- The sister chromatids by convention are now called sister chromosomes as they move toward opposing poles.

Telophase II

- It is similar to telophase I, and is marked by uncoiling and lengthening of the chromosomes and the disappearance of the microtubules.
- Nuclear envelopes reform and cleavage or cell wall formation eventually produces a total of four daughter cells, each with a haploid set of chromosomes. Meiosis is now complete.

Significance of meiosis:

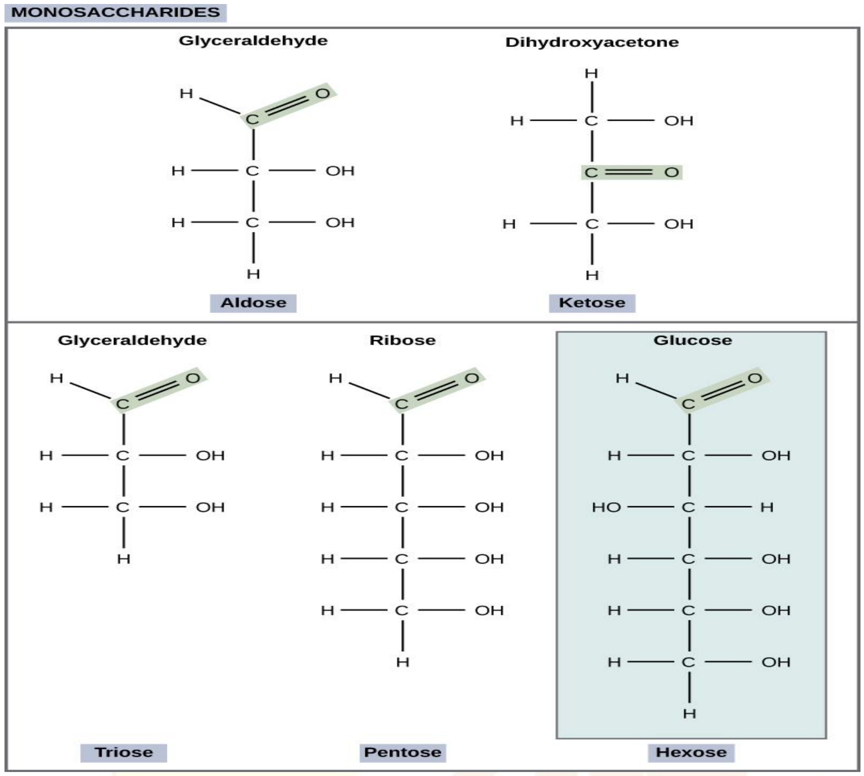
- Meiosis facilitates stable sexual reproduction. Without the halving of ploidy, or chromosome count, fertilization would result in zygotes that have twice the number of chromosomes than the zygotes from the previous generation.
- Successive generations would have an exponential increase in chromosome count, resulting in an unwieldy genome that would cripple the reproductive fitness of the species.

BIOCHEMISTRY

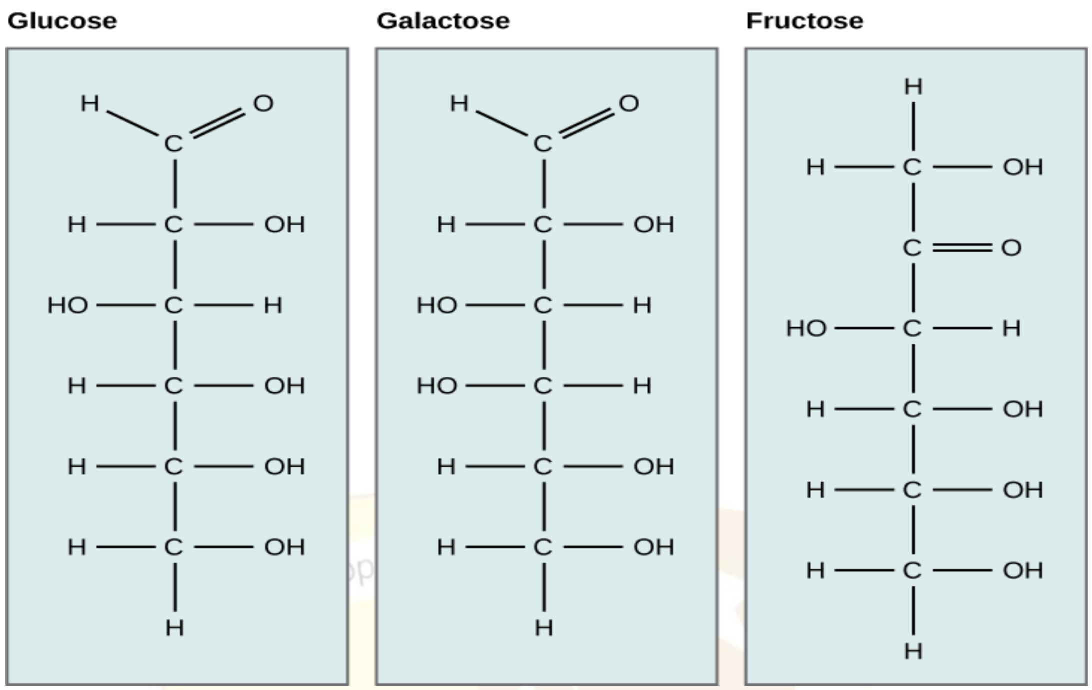
1. Macromolecules-building block biomolecules - metabolic intermediatesprecursors).
2. Carbohydrates. Classification; structure and functions of simple sugars and compound carbohydrates.
3. Lipids. Classification. Complex lipids, Simple lipids and derived lipids; Fatty acids saturated and unsaturated, triacyl glycerols, phospholipids, sphingolipids.
4. Amino acids, peptides and proteins. Amino acids: classification based on polarity; zwitterions, Dipeptides.
5. Proteins: Primary, secondary, tertiary and quarternry structures of proteins. Native comformation and biological functions of proteins. Denaturation and renaturation.
6. Nucleotides structure of nucleotides. Functions of nucleotides and nucleotide derivatives.
7. Secondary metabolites. A brief account of secondary metabolites, physiological roles. Significance: ecological importance.
8. Enzymes Classification (IUB), Mechanism of enzyme action, optimization of weak interactions in the transition state. Co-enzymes, inhibition, regulation: allosteric enzymes, covalently modulated enzymes. Isoenzymes.

CARBOHYDRATE

- Classification
  - Monosaccharides: They consist of one sugar containing 3,4,5,6 and 7 carbon atoms and are usually colorless, water-soluble, crystalline solids. Some monosaccharides have), fructose (levulose), galactose, a sweet taste. Examples of monosaccharides include glucose (dextrose xylose and ribose.
  - Disaccharides a sugar (a carbohydrate) composed of two monosaccharides.
  - Oligosaccharide An oligosaccharide is a saccharide polymer containing a small number (typically 3-10 monosaccharides).
  - Polysacharides are relatively complex carbohydrates. They are polymers made up of many monosaccharides joined together by glycosidic bonds. They are insoluble in water, and have no sweet taste.



- Glucose is an important source of energy. During cellular respiration, energy is released from glucose, and that energy is used to help make adenosine triphosphate (ATP).
- Plants synthesize glucose using carbon dioxide and water, and glucose in turn is used for energy requirements for the plant. Excess glucose is often stored as starch that is catabolized (the breakdown of larger molecules by cells) by humans and other animals that feed on plants.
- Galactose and fructose are other common monosaccharides — galactose is found in milk sugars and fructose is found in fruit sugars. Although glucose, galactose, and fructose all have the same chemical formula ($C_6H_{12}O_6$), they differ structurally and chemically (and are known as isomers) because of the different arrangement of functional groups around the asymmetric carbon



- Polysaccharide
  - A long chain of monosaccharides linked by glycosidic bonds is known as a **polysaccharide**.
  - Starch, glycogen, cellulose, and chitin are primary examples of polysaccharides.
  - Starch is the stored form of sugars in plants and is made up of a mixture of amylose and amylopectin (both polymers of glucose).
  - Starch is made up of glucose monomers that are joined by α 1-4 or α 1-6 glycosidic bonds.
  - **Glycogen** is the storage form of glucose in humans and other vertebrates and is made up of monomers of glucose.
  - Glycogen is the animal equivalent of starch and is a highly branched molecule usually stored in liver and muscle cells.
  - Whenever blood glucose levels decrease, glycogen is broken down to release glucose in a process known as glycogenolysis.
  - **Cellulose** is the most abundant natural biopolymer. The cell wall of plants is mostly made of cellulose; this provides structural support to the cell.
  - Wood and paper are mostly cellulosic in nature. Cellulose is made up of glucose monomers that are linked by β 1-4 glycosidic bonds.

Lipids

Non polar hydrophobic compounds

- Simple lipids
  - Are alcohol esters of fatty acid
  - Two types :neutral aft and waxes
- Waxes
  - Esters of long chain fatty acid and long chain non glycerol,aliphatic and monohydric alcohol
  - Mixtures of esters and ether
  - Examples
    - Beeswax,carnauba wax,sperm whale oil,sperm whale oil,wool fat
- Neutral fat
  - Mixture of triacylglycerol
  - Esters of fatty acid and glycerol
  - Fatty acid
    - Aliphatic hydrocarbon chain, with a carboxyl group at one end
    - Amphipathic molecule :molecule which contain both nonpolar and polar group
- Saturated and unsaturated fatty acid
  - Maximum possible no of hydrogen attached to the carbon back bone - saturated
  - Fatty acids with double bond –unsaturated fatty acid
- Essentail and non essential aminoacid
  - Essential amino acid:obtained through diet
  - Non essential :synthesised in hour body
- Glycerol
  - Straight chain trihydroxy alcohol
  - Ester bond
  - Glycerol esterified for one fatty acid : monoglyceride
- Compound lipid
  - Lipid which linked with non lipid molecule
  - Examples :phospholipids, glycolipids, lipoprotein
- Phospholipids
  - Heterogenous group of polar lipids
  - Constituent are phosphate group, glycerol,fatty acid , nitrogenous base , alcohol
  - Examples
    - Phosphoglycerides
      - Diglyceride
      - Fatty acd esters of glycerol phosphate
    - Lecithin
      - Cholin derivative of phosphatidic acid
    - Cephalin
      - Ethanolamine derivative of phosphatidic acid

- Sphingomyelin
    - Derivative of sphingenin
    - Abundant in brain , blood plasma, nervous tissue
- Plasmologen
    - Ether lipids
    - Formed of long chain aldehyde , fatty acid ,nitrogenous alcohol and glycerol lipids
- Cardiolipin
    - Phospholipid hapten
    - Mitochondrial dysfunction, ageing
- Prostaglandins
    - Derivative of 20 carbon essential amino acid
    - First extracted from human seminal fluid
    - Regulators of hormonal action
- Thromboxane
    - Direct derivative of prostaglandins
    - Regulate activity of blood platelet
- Glycolipids
    - Abundant in chloroplast
    - Suger lipid complexes
    - Examples ceribrocides-simplest , abundant in brain
- Sulpholipids
    - Sulphur containing compound lipids
    - Acidic
- Isoprenoid
    - 5 carbon structural unit - isoprene
    - Examples terpenes and steroids
- Terpens
    - Unsaturated hydrocarbons
    - Formula $C_{10}H_{16}$
    - Essential constituent of rubber,carotenoids
- Steroids
    - Saturated and poly cyclic compounds
    - Sterol from animal- zoosterol
    - Plant- phytosterol
    - Ergosterol is the yeast sterol
- Biological function of lipids
    - Energy storage
    - Electrotransport system
    - Involve in oxidative metabolism
    - Structural frame work

- Activator of enzyme
- Protect from mechanical damage
-

Amino acids

- **Amino acids** are organic compounds that combine to form proteins. **Amino acids** and proteins are the building blocks of life. When proteins are digested or broken down, **amino acids** are left. The human body uses **amino acids** to make proteins to help the body: Break down food.
- **Peptides** are short strings of amino acids, typically comprising 2–50 amino acids. Amino acids are also the building blocks of proteins, but proteins contain more. **Peptides** may be easier for the body to absorb than proteins because they are smaller and more broken down than proteins
- **Proteins** are large biomolecules, or macromolecule, consisting of one or more long chains of amino acids.
- **Amino acid classification based on polarity**
  - There are basically four different classes of amino acids determined by different side chains: (1) non-polar and neutral, (2) polar and neutral, (3) acidic and polar, (4) basic and polar.

- **Non-Polar Side Chains:**
  - Side chains which have pure **hydrocarbon** alkyl groups (alkane branches) or aromatic (benzene rings) are **non-polar**. Examples include valine, alanine, leucine, isoleucine, phenylalanine.
- **Polar Side Chains**
  - Side chains which have various functional groups such as **acids, amides, alcohols, and amines** will impart a **more polar** character to the amino acid. The ranking of polarity will depend on the relative ranking of polarity for various functional groups as determined in functional groups. In addition, the number of carbon-hydrogens in the alkane or aromatic portion of the side chain should be considered along with the functional group.
  - Example: serine
- **Acidic Side Chains:**
  - If the side chain contains an acid functional group, the whole amino acid produces an acidic solution. Normally, an amino acid produces a nearly neutral solution since the acid group and the basic amine group on the root amino acid neutralize each other in the zwitterion. If the amino acid structure contains two acid groups and one amine group, there is a net acid producing effect. The two acidic amino acids are aspartic and glutamic.
- **Basic Side Chains:**
  - If the side chain contains an amine functional group, the amino acid produces a basic solution because the extra **amine** group is not neutralized by the acid group. Amino acids which have basic side chains include: lysine, arginine, and histidine.

- Zwitterions are superior superhydrophilic materials with both cationic and anionic moieties, which can provide electrostatic interaction sites with water molecules to form dense and stable hydration layer, and then form strong repellency for competitive molecules.
- A zwitterion has a negative carboxylate ion and ammonium ion. The pH at which the concentration of the zwitterion predominates is the **isoionic point**. For neutral amino acids, the isoionic point lies halfway between the pK_α values of the carboxylic acid group and the ammonium group.

Dipeptides

- A dipeptide is a molecule consisting of two amino acids joined by a single peptide bond.
- Hydrolysis
  - Decomposition of a chemical compound by reaction with water, such as the dissociation of a dissolved salt or the catalytic conversion of starch to glucose.
- Oligopeptide
  - An oligopeptide (oligo=few) consists of between two and 20 amino acids (includes dipeptides, tripeptides, tetrapeptides, pentapeptides, etc.).
- Peptidase
  - An enzyme that catalyzes the hydrolysis of peptides into amino acids.
- Polypeptide
  - A peptide, such as a small protein, containing many molecules of amino acids, typically between 10 and 100.

PROTEINS

Structures of Proteins:

Primary Structure of Proteins:

Primary structure of proteins refers to the total number of amino acids and their sequence in that particular protein.

Secondary Structure of Proteins:

Alpha helix: Here the polypeptide is twisted or coiled to form a right handed helical structure. The distance between each turn of the coil is 5.4 Å.

(b) Beta pleated

Here the chain is not helical but zigzag. The distance between each turn is 7 Å. Polypeptide chains are arranged side by side in the form of pleats.

Tertiary Structure of Proteins:

The helical form of polypeptide folds into spherical, globular, ellipsoidal or other conformation, which is called the tertiary structure of proteins. This folding is necessary for the biological activity of the proteins. e.g., enzymes, immunoglobulin's.

Quaternary Structure of Proteins:

Quaternary structure refers to the type of arrangement of the polypeptides in an oligomeric protein. These polypeptides are held together by either hydrogen bonds, ionic bonds or Vander Waals' forces, e.g., Hemoglobin

Biological functions

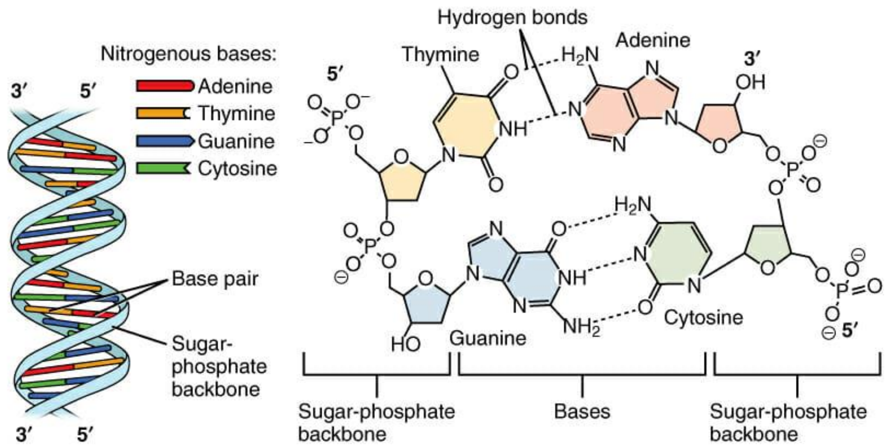
- Enzymes are proteins that facilitate biochemical reactions, for example, pepsin is a digestive enzyme in your stomach that helps to break down proteins in food.
- Antibodies are proteins produced by the immune system to help remove foreign substances and fight infections.
- DNA-associated proteins regulate chromosome structure during cell division and/or play a role in regulating gene expression, for example, histones and cohesin proteins
- Contractile proteins are involved in muscle contraction and movement, for example, actin and myosin
- Structural proteins provide support in our bodies, for example, the proteins in our connective tissues, such as collagen and elastin.
- Hormone proteins co-ordinate bodily functions, for example, insulin control our blood sugar concentration by regulating the uptake of glucose into cells.
- Transport proteins move molecules around our bodies, for example, haemoglobin transports oxygen through the blood.

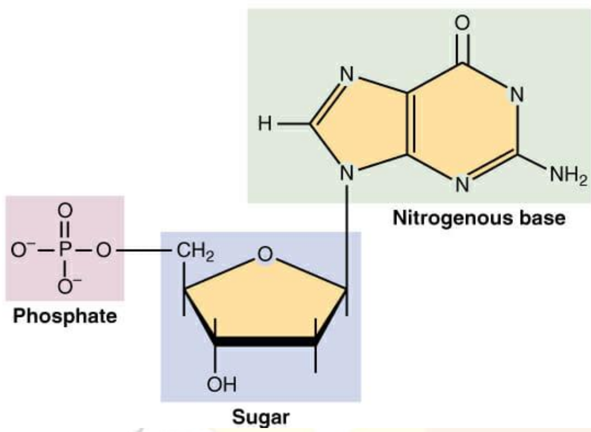
Denaturation and renaturation of protein

When a solution of a **protein** is boiled, the **protein** frequently becomes insoluble, it is **denatured**—and remains insoluble even when the solution is cooled. In some instances the original structure of the **protein** can be regenerated; the process is called **renaturation**.

Nucleotide

<u>Structure of nucleotide</u>





Primary Structure of Nucleic Acids:

The sequence or order of the nucleotides defines the primary structure of DNA and RNA. The nucleotides of the polymer are linked by phosphodiester bonds connecting through the oxygen on the 5' carbon of one to the oxygen on the 3' carbon of another. The Oxygen and Nitrogen atoms in the backbone give DNA and RNA "polarity".

Secondary Structure of Nucleic Acids:

A purine base always pairs with a pyrimidine base or more specifically Guanosine (G) with Cytosine (C) and Adenine (A) with Thymine (T) or Uracil (U).

DNA: The secondary structure of DNA consists of two polynucleotide chains wrapped around one another to form a double helix. The orientation of the helix is usually right handed with the two chains running antiparallel to one another.

Complementarity:

The sequence of bases on each strand are arranged so that all of the bases on one strand pair with all of the bases on another strand, i.e. the number of guanosines always equals the number of cytosines and the number of adenines always equals the number of thymines.

There are two grooves, one major and one minor, on the double helix. Proteins and drugs interact with the functional groups on the bases that are exposed in the grooves.

- Functions
  - Nucleotides are precursors of the nucleic acids, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

  • The nucleic acids are concerned with the storage and transfer of genetic information.

  • The universal currency of energy, namely ATP, is a nucleotide derivative. • Nucleotides are also components of important co-enzymes like - NAD+ and FAD, and - metabolic regulators such as cAMP and cGMP.

  <u>Niacinamide adenine dinucleotide (NAD)</u>

  - Coenzyme 1
  - Formed of one molecule of adenine ,one molecule of niacinamide ,2 molecule eibose, 2 molecule pf inorganic phosphate
  - Functions
    - Co enzyme of dehydrogenase
    - Oxidizing agent

<u>Flavin adenine dinucleotide (FAD)</u>

- Vitaminous co enzyme
- Two portions
  - Flavin ribitol monophosphate
  - Adenosine monophosphate
- Functions
  - Derivative of riboflavin or vitamine B $_{12}$
- Pseudonucleotide

Adinosine triphosphate

- Formed of an adenine molecule , a ribose molecule, triphosphate
- AMP,ADP,ATP
- Interconversion is mediated by the enzyme adenylate kinase
- The active form of ATP is usuallyusually complexed with Mg^{2+},Mn^{2+},Ca^{2+}
- Very high phosphate group transfer potential
- Function
  - Source of energy for biosynthetic processes
  - Function as a phosphorylating agent
  - Reservoir of chemical bond energy
  - Carrier of chemical energy

Cyclic AMP

- Important regulator of metabolic processes in prokaryote and animals
- Formed of adenine ,ribose and inorganic phosphate
- Functions
  - Second messenger
  - Stimulates the enhanced synthesis of hormone
  - Function as an acrasin
  - Active role in gene regulation
  - Raises blood glucose level
  - Stimulate glycogenolysis
  - Stimulate lipolysis and fat mobilization
  - Modifies and regulate cell cycle

Cyclic GMP

- Cyclic form of the nucleotide adenosine monophosphate
- It is formed from GTP by the action of guanyl cyclase
- Phosphorylates the myosin of the smooth muscles of blood vessel.
- It act as a negative feedback signal to speed up the removal of intracellular calcium

Abdul Faisal P.
Dept. of Botany

Principal
CPA College of Arts & Science