SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
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SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOTECHNOLOGY

UNIT – I – CELL BIOLOGY – SBB1101

SBB1101	CELL BIOLOGY	L	T	P	Credits	Total Marks
		3	1	0	4	100

COURSE OBJECTIVES

- Cell biology is the study of the structure and function of prokaryotic and eukaryotic cells. In this course the students will learn different areas of cellular biology including the structure and functions of cell, its organelles, synthesis and function of macromolecules such as carbohydrate, protein, lipid, DNA & RNA; membrane structure and function; bioenergetics; cellular communication; and microscopic techniques to understand the cell structure.

UNIT 1 FUNDAMENTALS OF CELL STRUCTURE **12 Hrs.**

Discovery of cells; Basic properties of cells; Different classes of cells – Prokaryotic and eukaryotic cells. Cell division: Cell cycle; mitosis; meiosis, binary fission.

UNIT 2 CELLULAR MEMBRANES AND MATRICES **12 Hrs.**

Chemical composition and fluidity of membranes; dynamic nature of membranes; transportation across cell membrane; membrane potentials; extracellular matrices – structure and function; cytoskeleton – structure and function.

UNIT 3 CELLULAR ORGANELLES IN ENERGY METABOLISM **12 Hrs.**

Mitochondria – structure and function; Chloroplast – structure and function. Structure of nucleus – nuclear membrane, nucleolus, chromatin, structure of nucleic acids

UNIT 4 CELLULAR ORGANELLES IN METABOLISM **12 Hrs.**

Endoplasmic reticulum – smooth & rough; function of endoplasmic reticulum; Golgi complex – structure and function; Ribosomes – Types, structure and function; Morphology and functions of peroxisomes and glyoxisomes; Plant cell vacuoles.

UNIT 5 TRANSPORT ACROSS CELL MEMBRANE **12 Hrs.**

Passive and active transports, Permeases, Sodium -potassium pumps, Ca 2+ ATPase pump, ATP dependant proton pumps, co-transport, symport, antiport, Endocytosis and Exocytosis. Introduction to intra and extra cellular products of medicinal use.

Max Hours.60

Text Books

1. Freifelder D. 1985. Molecular Biology, Narosa Publishing House. New Delhi.
2. Lewin B. 2007. Genes IX. Oxford University Press, London.
3. Ajoy Paul. 2011. Textbook of Cell and Molecular Biology. Books and Allied Ltd.
4. Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. 2008. Molecular Biology of Cell. 6th Edition. Garland Science, Taylor & Francis group Publishers.
5. Harvey Lodish, Arnold Berk, S Lawrence Zipursky, Paul Matsudaira, David Baltimore, and James Darnell. 1995. Molecular Cell Biology. 3rd Edition. W.H. Freeman Publishers.

END SEMESTER EXAMINATION QUESTION PAPER PATTERN

Max. Marks : 100 **Exam Duration : 3 Hrs.**

PART A : 10 questions of 2 marks each - No choice **20 Marks**

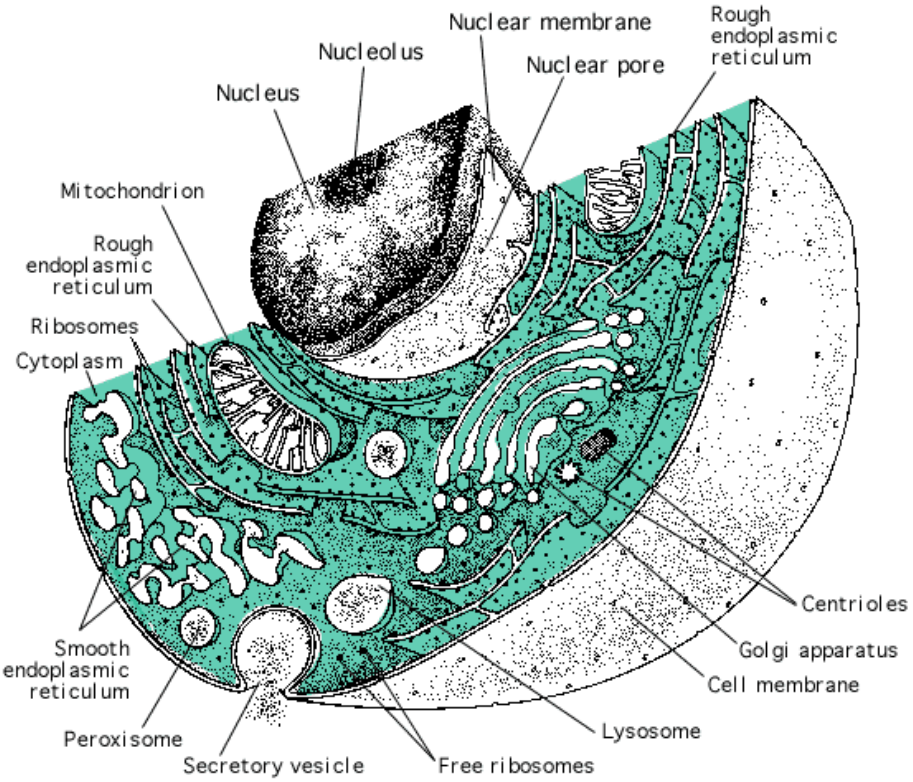
PART B : 2 questions from each UNIT of internal choice; each carrying 16 marks **80 Marks**

UNIT:1

CELL THEORY

The microscopes we use today are far more complex than those used in the 1600s by Antony van Leeuwenhoek, a Dutch shopkeeper who had great skill in crafting lenses. Despite the limitations of his now-ancient lenses, van Leeuwenhoek observed the movements of protista (a type of single-celled organism) and sperm, which he collectively termed "animalcules. "

In a 1665 publication called *Micrographia*, experimental scientist Robert Hooke coined the term "cell" for the box-like structures he observed when viewing cork tissue through a lens. In the 1670s, van Leeuwenhoek discovered bacteria and protozoa. Later advances in lenses, microscope construction, and staining techniques enabled other scientists to see some components inside cells.



Structure of an Animal Cell: The cell is the basic unit of life and the study of the cell led to the development of the cell theory.

By the late 1830s, botanist Matthias Schleiden and zoologist Theodor Schwann were studying tissues and proposed the unified cell theory. The unified cell theory states that: all living things are composed of one or more cells; the cell is the basic unit of life; and new cells arise from existing cells. Rudolf Virchow later made important contributions to this theory.

Schleiden and Schwann proposed spontaneous generation as the method for cell origination, but spontaneous generation (also called abiogenesis) was later disproven. Rudolf Virchow famously stated "Omnis cellula e cellula"… "All cells only arise from pre-existing cells. "The parts of the theory that did not have to do with the origin of cells, however, held up to scientific scrutiny and

are widely agreed upon by the scientific community today. The generally accepted portions of the modern Cell Theory are as follows:

1. The cell is the fundamental unit of structure and function in living things.
2. All organisms are made up of one or more cells.
3. Cells arise from other cells through cellular division.

The expanded version of the cell theory can also include:

- Cells carry genetic material passed to daughter cells during cellular division
- All cells are essentially the same in chemical composition
- Energy flow (metabolism and biochemistry) occurs within cells

What are the 9 basic properties of cell?

1. Cells are Highly Complex and Organized
2. Cells Possess a Genetic Program and the Means to Use it
3. Cells need Organic Compounds to Generate Essential Macromolecules
4. Cells are dependent to Water, making up more than 70% of the cell
5. Cells are Capable of Producing More of Themselves
6. Cells Acquire and Utilize Energy
7. Cells Carry Out a Variety of Chemical Reactions
8. Cells Engage in Mechanical Activities
9. Cells Die very Fast and Regenerate very Fast to Make New Cells
10. Cells are Able to Respond to Stimuli
11. Cells Are Capable of Self-Regulation
12. Cells Evolve

Prokaryotic Cells

All cells share four common components:

1. a plasma membrane: an outer covering that separates the cell's interior from its surrounding environment.
2. cytoplasm: a jelly-like cytosol within the cell in which other cellular components are found
3. DNA: the genetic material of the cell
4. ribosomes: where protein synthesis occurs

However, prokaryotes differ from eukaryotic cells in several ways.

A prokaryote is a simple, single-celled (unicellular) organism that lacks an organized nucleus or any other membrane-bound organelle. We will shortly come to see that this is significantly different in eukaryotes. Prokaryotic DNA is found in a central part of the cell: the nucleoid.

Most prokaryotes have a peptidoglycan cell wall and many have a polysaccharide capsule. The cell wall acts as an extra layer of protection, helps the cell maintain its shape, and prevents dehydration. The capsule enables the cell to attach to surfaces in its environment. Some prokaryotes have flagella, pili, or fimbriae. Flagella are used for locomotion. Pili are used to exchange genetic

material during a type of reproduction called conjugation. Fimbriae are used by bacteria to attach to a host cell.

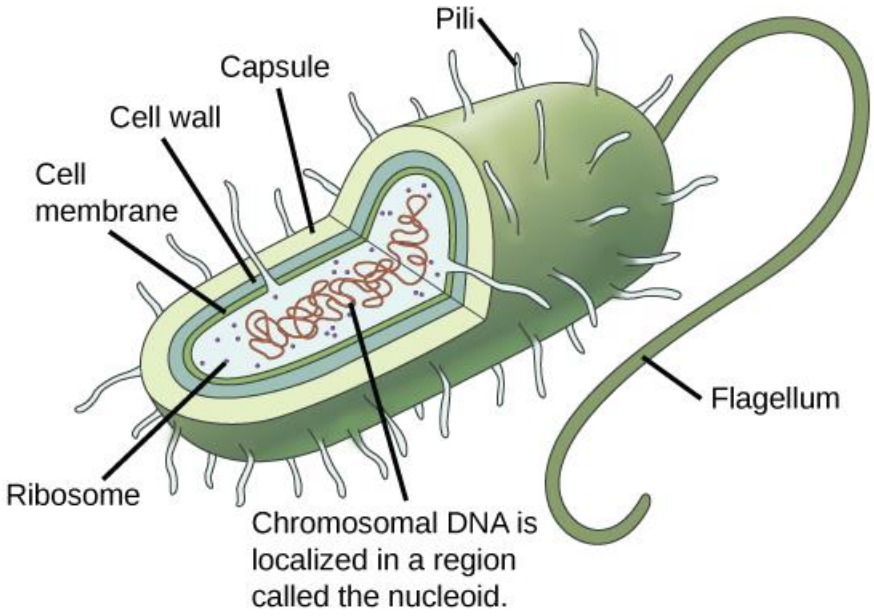


Figure 4.2A.14.2A.1: **General Structure of a Prokaryotic Cell**: This figure shows the generalized structure of a prokaryotic cell.All prokaryotes have chromosomal DNA localized in a nucleoid, ribosomes, a cell membrane, and a cell wall.The other structures shown are present in some, but not all, bacteria.

Cell Size

At 1 µm to 5 µm in diameter, prokaryotic cells are significantly smaller than eukaryotic cells, which have diameters ranging from 10 to 100 µm. The small size of prokaryotes allows ions and organic molecules that enter them to quickly diffuse to other parts of the cell. Similarly, any wastes produced within a prokaryotic cell can quickly diffuse out. This is not the case in eukaryotic cells, which have developed different structural adaptations to enhance intracellular transport.

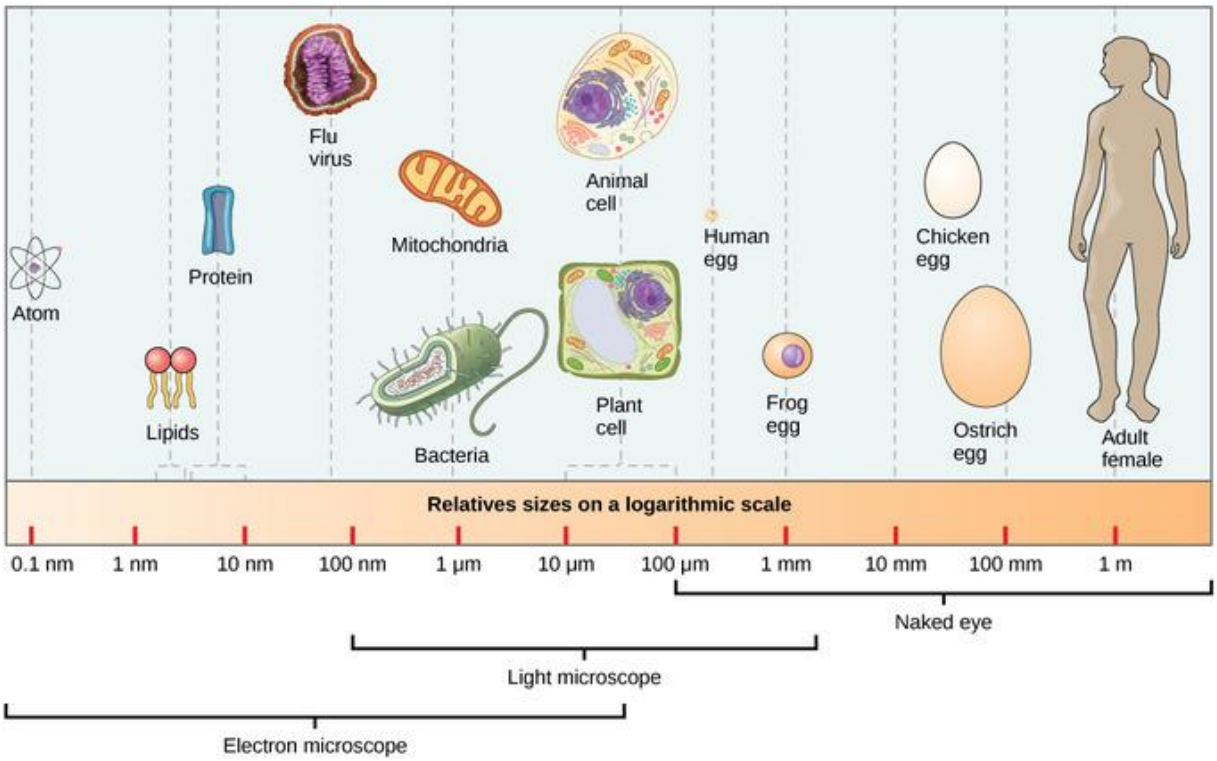


Figure 4.2A.14.2A.1: **Microbial Size**: This figure shows relative sizes of microbes on a logarithmic scale (recall that each unit of increase in a logarithmic scale represents a 10-fold increase in the quantity being measured).

Small size, in general, is necessary for all cells, whether prokaryotic or eukaryotic. Let's examine why that is so. First, we'll consider the area and volume of a typical cell. Not all cells are spherical in shape, but most tend to approximate a sphere. You may remember from your high school geometry course that the formula for the surface area of a sphere is $4\pi r^2$, while the formula for its volume is $4/3\pi r^3$. Thus, as the radius of a cell increases, its surface area increases as the square of its radius, but its volume increases as the cube of its radius (much more rapidly). Therefore, as a cell increases in size, its surface area-to-volume ratio decreases. This same principle would apply if the cell had the shape of a cube. If the cell grows too large, the plasma membrane will not have sufficient surface area to support the rate of diffusion required for the increased volume. In other words, as a cell grows, it becomes less efficient. One way to become more efficient is to divide; another way is to develop organelles that perform specific tasks. These adaptations led to the development of more sophisticated cells called eukaryotic cells.

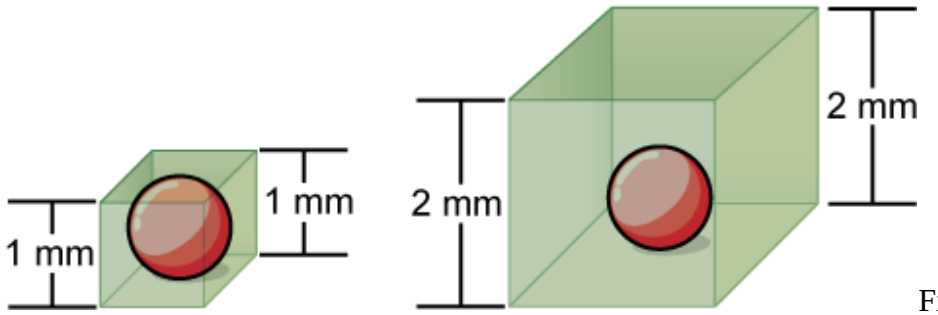


Figure 4.2A.14.2A.1: **Cell Surface Size**: Notice that as a cell increases in size, its surface area-to-volume ratio decreases.When there is insufficient surface area to support a cell's increasing volume, a cell will either divide or die.The cell on the left has a volume of 1 mm3 and a surface area of 6 mm2, with a

surface area-to-volume ratio of 6 to 1, whereas the cell on the right has a volume of 8 mm3 and a surface area of 24 mm2, with a surface area-to-volume ratio of 3 to 1

Eukaryotic Cell Structure

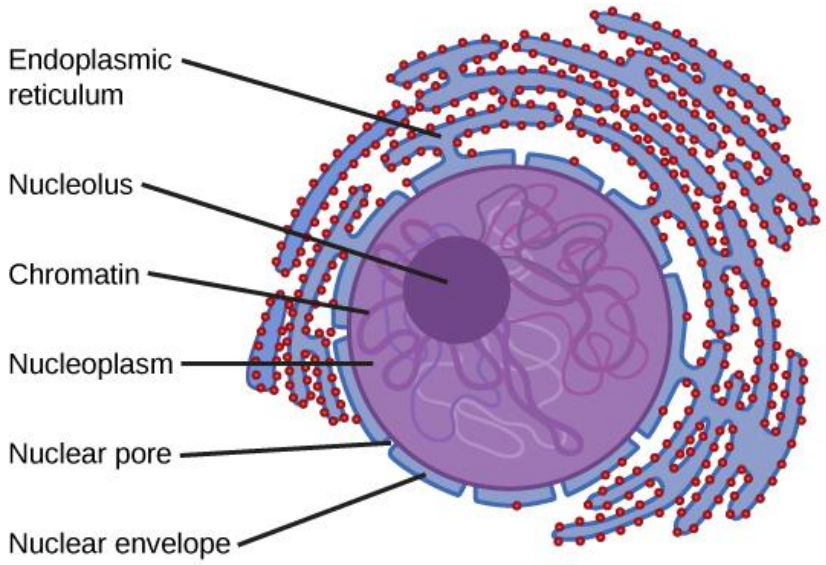
Like a prokaryotic cell, a eukaryotic cell has a plasma membrane, cytoplasm, and ribosomes. However, unlike prokaryotic cells, eukaryotic cells have:

1. a membrane-bound nucleus
2. numerous membrane-bound organelles (including the endoplasmic reticulum, Golgi apparatus, chloroplasts, and mitochondria)
3. several rod-shaped chromosomes

Because a eukaryotic cell's nucleus is surrounded by a membrane, it is often said to have a "true nucleus. " Organelles (meaning "little organ") have specialized cellular roles, just as the organs of your body have specialized roles. They allow different functions to be compartmentalized in different areas of the cell.

The Nucleus & Its Structures

Typically, the nucleus is the most prominent organelle in a cell. Eukaryotic cells have a true nucleus, which means the cell's DNA is surrounded by a membrane. Therefore, the nucleus houses the cell's DNA and directs the synthesis of proteins and ribosomes, the cellular organelles responsible for protein synthesis. The nuclear envelope is a double-membrane structure that constitutes the outermost portion of the nucleus. Both the inner and outer membranes of the nuclear envelope are phospholipid bilayers. The nuclear envelope is punctuated with pores that control the passage of ions, molecules, and RNA between the nucleoplasm and cytoplasm. The nucleoplasm is the semi-solid fluid inside the nucleus where we find the chromatin and the nucleolus. Furthermore, chromosomes are structures within the nucleus that are made up of DNA, the genetic material. In prokaryotes, DNA is organized into a single circular chromosome. In eukaryotes, chromosomes are linear structures.



Eukaryotic Nucleus: The nucleus stores chromatin (DNA plus proteins) in a gel-like substance called the nucleoplasm.The nucleolus is a condensed region of chromatin where ribosome synthesis occurs.The boundary of the nucleus is called the nuclear envelope.It consists of two phospholipid bilayers: an outer membrane and an inner membrane.The nuclear membrane is continuous with the endoplasmic reticulum.Nuclear pores allow substances to enter and exit the nucleus.

Other Membrane-Bound Organelles

Mitochondria are oval-shaped, double membrane organelles that have their own ribosomes and DNA. These organelles are often called the "energy factories" of a cell because they are responsible for making adenosine triphosphate (ATP), the cell's main energy-carrying molecule, by conducting cellular respiration. The endoplasmic reticulum modifies proteins and synthesizes lipids, while the golgi apparatus is where the sorting, tagging, packaging, and distribution of lipids and proteins takes place. Peroxisomes are small, round organelles enclosed by single membranes; they carry out oxidation reactions that break down fatty acids and amino acids. Peroxisomes also detoxify many poisons that may enter the body. Vesicles and vacuoles are membrane-bound sacs that function in storage and transport. Other than the fact that vacuoles are somewhat larger than vesicles, there is a very subtle distinction between them: the membranes of vesicles can fuse with either the plasma membrane or other membrane systems within the cell. All of these organelles are found in each and every eukaryotic cell.

Animal Cells Versus Plant Cells

While all eukaryotic cells contain the aforementioned organelles and structures, there are some striking differences between animal and plant cells. Animal cells have a centrosome and lysosomes, whereas plant cells do not. The centrosome is a microtubule-organizing center found near the nuclei of animal cells while lysosomes take care of the cell's digestive process.

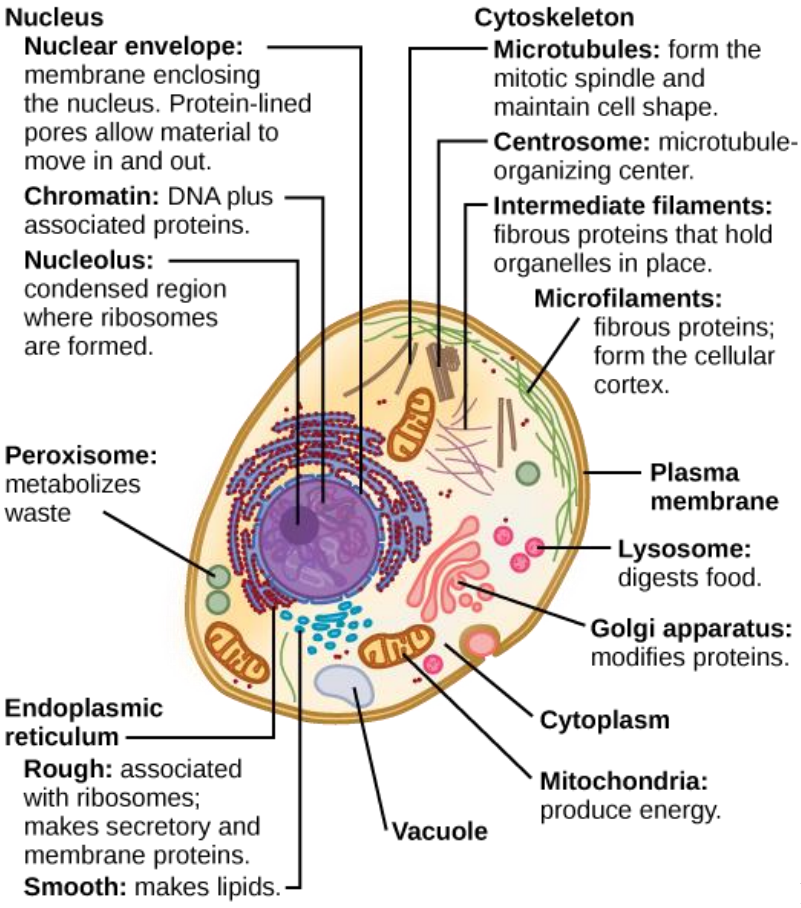


Figure 4.3A.14.3A.1: **Animal Cells**: Despite their fundamental similarities, there are some striking differences between animal and plant cells. Animal cells have centrioles, centrosomes, and lysosomes, whereas plant cells do not.

In addition, plant cells have a cell wall, a large central vacuole, chloroplasts, and other specialized plastids, whereas animal cells do not. The cell wall protects the cell, provides structural support, and gives shape to the cell while the central vacuole plays a key role in regulating the cell's concentration of water in changing environmental conditions. Chloroplasts are the organelles that carry out photosynthesis.

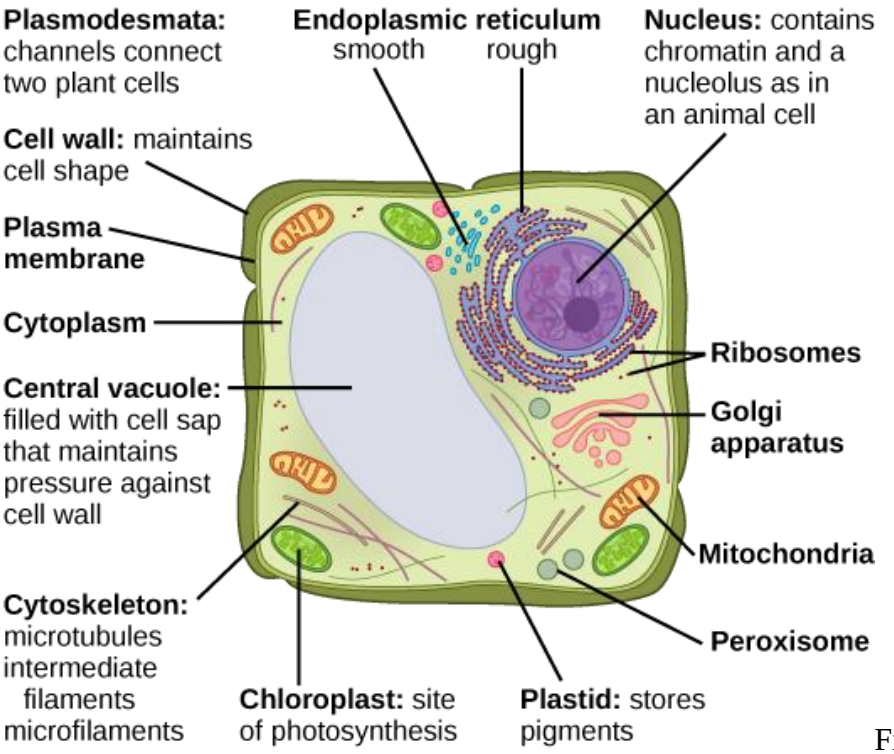
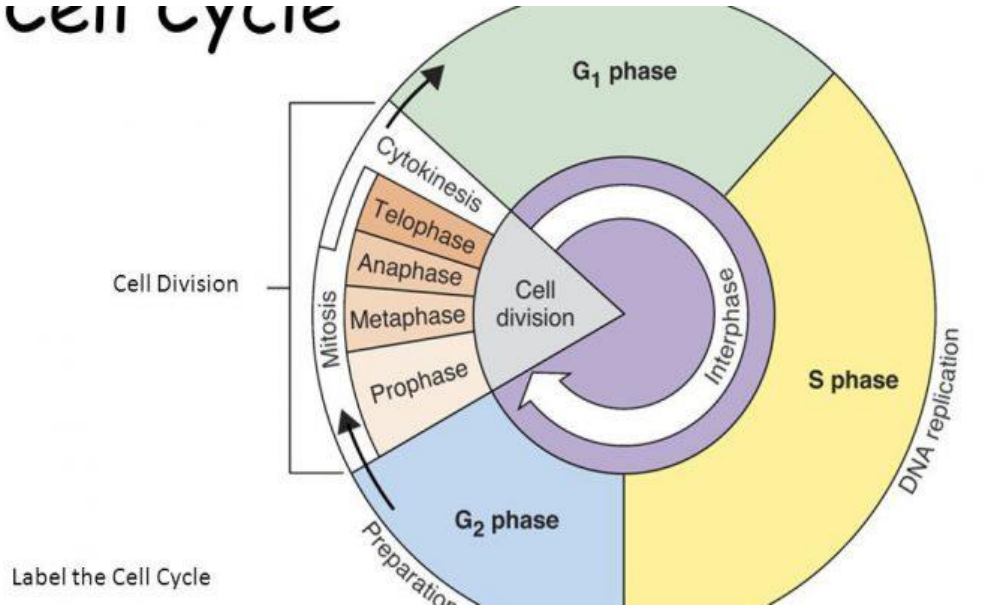


Figure 4.3A.14.3A.1: **Plant Cells**: Plant cells have a cell wall, chloroplasts, plasmodesmata, and plastids used for storage, and a large central vacuole, whereas animal cells do not.

CELL CYCLE: PHASES OF CELL CYCLE



- In both unicellular and multicellular eukaryotes, the cell reproduction is a cyclic process of growth, nuclear division and usually cytoplasmic division called cell cycle.
- Cell cycle is a series of macromolecular events that lead to cell division and the production of two daughter cells, each containing chromosomes identical with those of the parental cell.

- Two main molecular processes take place during the cell cycle are duplication of parental chromosome during S phase and separation of chromosome equally to daughter cell during M phase.
- In somatic cell, the cell cycle consists of following four phase;
- G1 (gap 1) phase
- S (synthesis) phase
- G2 (gap2) phase
- M (mitosis) phase

1. G1 (gap1) phase:

- The first stage of interphase is called the G_1 phase (first gap) because, from a microscopic aspect, little change is visible. However, during the G_1 stage, the cell is quite active at the biochemical level.
- It is characterized by a change in chromosome from condensed state to more extended state and series of metabolic events that leads to initiation of DNA replication. During G1 phase, chromatin fibres become slender, less coiled and fully extended and more active for transcription. The transcription results in synthesis of RNAs (tRNA, mRNA and rRNA) ad series of proteins molecules required for initiation of DNA replication.
- The length of G1 phase varies from cell to cell and also the length of G1 phase is more than other three phase in cell cycle.
- G1 phase represents 25-40% of generation time of a cell.
- G1 phase is very significant phase of cell cycle as the cell grows and accumulates the building blocks of chromosomal DNA and the associated proteins as well as sufficient energy reserves to complete the task of replicating each chromosome.
- Within G1 phase there is a definite check point at which DNA synthesis is initiated and once the biochemical events associated with that point have occurred cell proceeds towards division.

2. S (synthesis) phase:

- The synthesis phase of interphase is biochemically a phase of active DNA synthesis and histone synthesis.
- In the S phase, chromosome numbers doubles which is accomplished by DNA replication and associated proteins. Although some of the histone protein synthesis occurs in G1 phase, most of it is synthesized during S phase.
- DNA replication is semi conservative and discontinuous type which results in the formation of identical pairs of DNA molecules.
- After doubling of chromosome, sister chromatids are still firmly attached to the centromeric region.
- At the center of each animal cell, the centrosomes of animal cells are associated with a pair of rod-like objects, the centrioles, which are at right angles to each other. Centrioles help organize cell division. Centrioles are absent in plants and most fungi.
- The centrosome (centriole) is also duplicated during the S phase. The two centrosomes will give rise to the mitotic spindle, the apparatus that mediate the movement of chromosomes during mitosis.

3. Gap2 (gap2) phase:

- G2 phase follows S phase. This phase represents 10-25% of generation time of cell.
- In G2 phase chromosome consists of two chromatids ie the cell has twice the amount of DNA content.
- In the G_2 phase, the cell restore its energy stores and synthesizes proteins necessary for chromosome manipulation.
- Some cell organelles are duplicated, and the cytoskeleton is dismantled to provide resources for the mitotic phase.
- There may be additional cell growth during G_2. The final preparations for the mitotic phase must be completed before the cell is able to enter the first stage of mitosis

4. M (mitotic) phase:

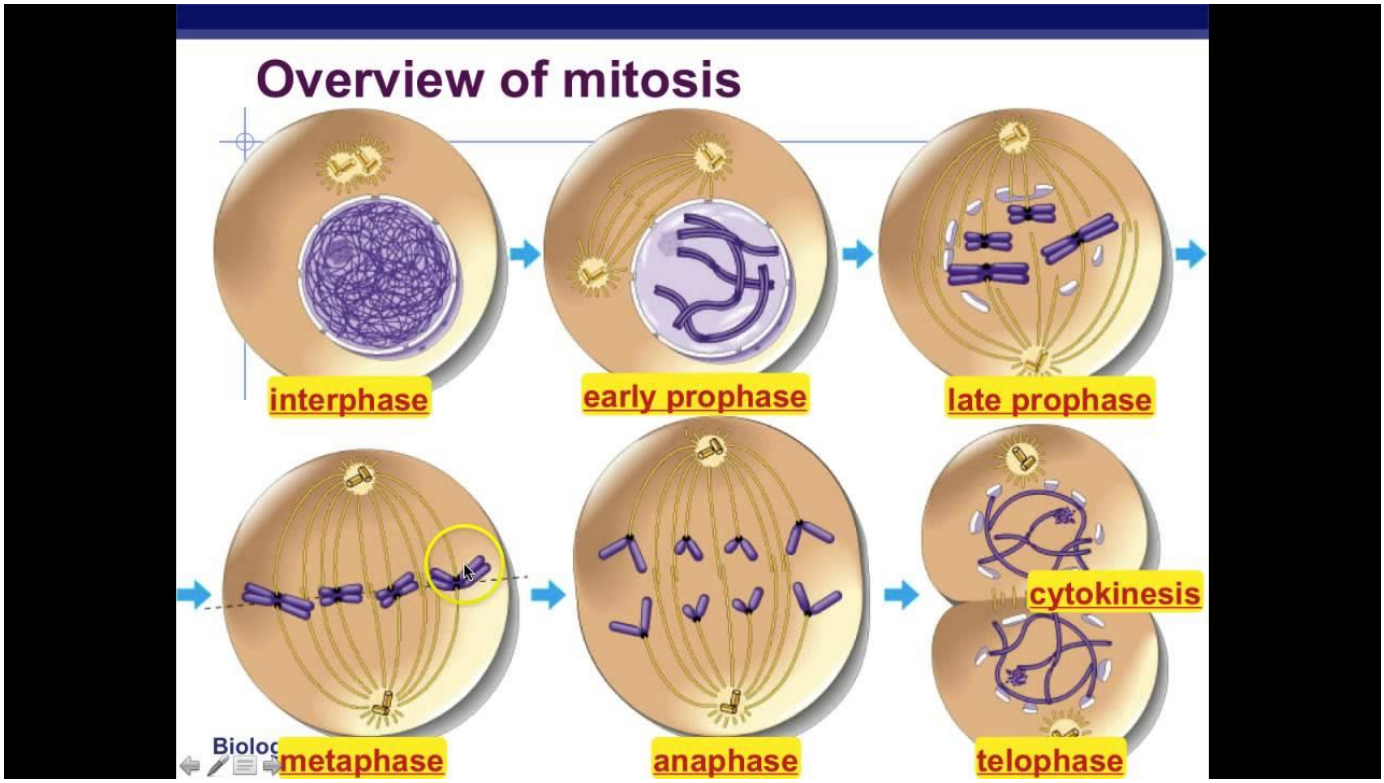
- M phase follows G2 phase. During this phase cell divides into two daughter cell with equal distribution of chromosome among daughter cells. After M phase cell enter into G1 phase and next cell cycle is repeated. However, some cell after completion of mitosis do not enter into G1 phase, those cell are referred as G0 cells.
- M phase consists of following sub –phases;
- **During prophase**, the nuclear membrane disappears, spindle fibers form, and DNA condenses into chromosomes (sister chromatids).
- **During metaphase**, the sister chromatids align along the equator of the cell by attaching their centromeres to the spindle fibers.
- **During anaphase**, sister chromatids are separated at the centromere and are pulled towards opposite poles of the cell by the mitotic spindle.
- **During telophase,** chromosomes arrive at opposite poles and unwind into thin strands of DNA, the spindle fibers disappear, and the nuclear membrane reappears.
- **Cytokinesis** is the actual splitting of the cell membrane; animal cells pinch apart, while plant cells form a cell plate that becomes the new cell wall.
- **Cells enter the G_0 (inactive)** phase after they exit the cell cycle when they are not actively preparing to divide; some cells remain in G_0 phase permanently.

MITOSIS: MITOTIC CELL DIVISION, STAGES AND SIGNIFICANCE

- Mitosis is a type of cell division in which single haploid cell (n) or diploid cell (2n) divides into two haploid or diploid daughter cells that are same as parent.
- Mitosis occurs in somatic cells of plants and animals. In this cell division, the two daughter cells have same number of chromosomes as that in the parent cells.

The process of mitosis consists of the following stages or phases:

1. **Interphase or Interkinesis**
2. **Karyokinesis**
3. **Cytokinesis**



1. Interphase or interkinesis

- Interphase is the phase between two successive cell division (end of one cell division to the beginning of next cell division).
- It is the longest phase in the cell cycle.
- Interphase looks dormant but it is metabolically active stage.

It is divided into 3 sub-stages viz. G_1-phase, S-phase and G_2-phase.

i. G_1-Phase or Gap-1 phase

- The cell grows in size due to active biosynthesis.
- Formation of structural and functional proteins.
- Synthesis of mRNA, tRNA and rRNA takes place.

ii. S-Phase or Synthetic phase

- Replication of DNA takes place.
- Synthesis of histone proteins takes place which covers DNA.

iii. G_2-Phase or Gap-two phase or Second growth phase

- RNA and protein is synthesize.
- Centrioles get replicate (in case of animal cell)
- Synthesis of spindle proteins takes place.

2. Karyokinesis

- Karyokinesis is the division of the nucleus.
- It consists of the following four phases.

i. Prophase

- It is the first visible stage in karyokinesis.
- The chromosomes appear as long coiled threads called chromatids.
- The chromatin becomes shorter, thicker and visible due to the condensation of DNA.
- The chromatins are now called chromosomes.
- Stainability of nucleus increase.
- Each chromosome starts to splits longitudinally into two sister chromatids. These sister chromatids are attached with each other at centromere.
- The nuclear membrane and nucleolus starts to disappear and by the end it will completely disappeared.

ii. Metaphase

- Nuclear membrane and nucleolus completely disappears and simultaneously appearance of spindle fibres
- Spindle fibres attached to the centromere of chromosome.
- The chromosomes are arranged on the equatorial plane.
- The process of gathering of chromosomes in equator is called congression and plate formed is called metaphasic plate.

iii. Anaphase

- The centromere of each chromosome splits into two sister chromatids and forms two daughter chromosomes.
- The daughter chromosomes are pulled towards the poles due to the contraction of spindle fibres and stretching of inter zonal fibres.
- During polar movement, the chromosomes shows different shapes i.e. J,U,V,L or I shaped in appearance.
- At the end of anaphase, each pole will get one set of daughter chromosomes.
- It is shortest phase and is also known as migratory phase.

iv. Telophase

- The daughter chromosomes reach respective poles and uncoil and become thin, long and visible.
- The spindle fibres start disappearing and finally disappear.
- The nuclear membrane and the nucleolus reappear.
- Two nuclei are formed at the end of telophase. Both the nuclei have the same number of chromosome as parent cell.

- It is the last visible stage of karyokinesis and is also known as reorganization phase.

3. Cytokinesis

- Cytokinesis is the division of the cytoplasm.
- In plant cells, cytokinesis occurs by cell plate formation.
- During cytokinesis, many granular matrix formed by the golgibody and endoplasmic reticulum accumulates in the equatorial region. These granular matrix form cell plate. This plate divides the cell and by the end of telophase, cytokinesis is completed.
- In animal cells, cytokinesis occurs by cleavage or furrow formation.

SIGNIFICANCE OF MITOSIS:

- Mitosis produces 2 genetically identical cells, so mitosis maintains the genetic stability of organisms.
- DNA remains constant, so mitosis keeps the chromosomes number constant in a species.
- Mitosis helps in the development of multicellular organism.
- Mitosis helps to replacement of old, dead or damaged cells by new one.
- It helps in the recovery of wounds and injury of the body by formation of new cells.
- In unicellular organisms like Yeast, *Paramecium* , mitosis is a means of asexual reproduction.
- Mitosis causes maturation and multiplication of germ cells and makes them ready for meiosis.

MEIOSIS: MEIOTIC CELL DIVISION, STAGES AND SIGNIFICANCE

- Meiosis is a cell division in which four haploid cells are formed from a single diploid cell.
- It usually occurs in reproductive organs or gonads of the organisms.
- Meiosis is also known as reductional cell division because four daughter cells produced contain half the number of chromosomes than that of their parent cell.

Meiosis has two nuclear division phases:

1. **Meiosis-I (Reductional or Heterotypic division)**
2. **Meiosis-II (Equational or Homotypic division)**

Meiosis-I (heterolytic or Reductional division)

Meiosis-I has four different phases or stages:

1. Prophase-I
2. Metaphase-I
3. Anaphase-I
4. Telophase-I

1. Prophase-I

- It occupies the longest duration in Meiosis-I.
- It is divided into five sub-stages or sub-phases.

i. Leptotene

- This phase starts immediately after interphase.
- The size of cell and nucleus increases
- The chromosomes appear long, uncoiled thread-like in structure bearing many bead-like structures called chromomeres.
- The nuclear membrane and nucleolus remain as it is.

ii. Zygotene

- Homologous chromosomes come closer and starts to pair up along their length.
- The pairing of homologous chromosomes is called Synapsis and the paired homologous chromosomes are referred as bivalents.
- The homologous chromosomes are held together by ribonuclear protein between them.

iii. Pachytene

- The chromosome become shorter and thicker.
- Each chromosome of the bivalents splits longitudinally to form two chromatids such that bivalents is composed of four strands and is known as a tetrad.
- The process of crossing over starts (crossing over; a small fragment of chromosome exchange between two non-sister chromatids of bivalent by breakage and rejoining).
- Crossing over is the most important genetic phenomenon of meiosis which causes variation in genetic characters in offspring.

iv. Diplotene

- In this stage crossing over takes place.
- Bivalents (chromatids) repel each other.
- Homologous chromosome (two non-sister chromatids) begins to separates but separation is not complete, they remains attached to a point with a knot like structure called chiasmata (singular – chiasma).
- The number of chiasmata varies. Depending upon the number of chiasmata, chromosome appears different shape.
    - 1 chiasmata: cross like
    - 2 chiasmata: ring like
    - Many chiasmata: series of loop
- Nuclear membrane and nucleolus begins to disappear.

v. Diakinesis

- The chiasma moves towards the end of the chromosomes (tetrad) due to contraction of chromosomelastly slips over separating the homologous chromosome. This movement of the chiasmata towards the end of chromosome is called terminalization.
- By the end of diakinesis the nuclear membrane and nuleolus get completely disappeared and the chromosomes are free in the cytoplasm.
- Spindle fibres begin to form

2. Metaphase-I

- The spindle fibres organized between two poles and get attached to the centromere of chromosomes.
- Chromosome moves to equator
- The bivalent chromosomes are arranged in the equatorial plate in such a way that 2 metaphasic plates are formed.

3. Anaphase-I

- Spindle fibres contracts and pulls the whole chromosomes to the polar region.
- The separated chromosome is known as dyads
- No splitting of chromosomes occurs so the centromere of each homologous chromosome does not divide. Thus, the chromosome number of the daughter nuclei is reduced to half.
- Now the separated chromosome moves toward opposite poles.

4. Telophase-I

- Two groups of chromosome formed at each pole and organized into nuclei.
- The nuclear membrane and nucleolus reappears.
- The chromosomes get uncoiled into chromatin thread.
- The spindle fibres disappear totally.

Cytokinesis I

- Cytokinesis may or may not follow nuclear division (meiosis-I Cytokinesis occurs by cell plate formation method in plant cell and furrowing method in animal cells.

Interphase II or Interkinesis

- The two cells or nuclei thus formed pass through a short stage called interphase-II. Sometimes, interphase-II is absent.
- It is the resting phase between meiosis-I and meiosis-II.
- It is either very short or may be absent
- No DNA synthesis occurs.

Meiosis-II (Homolytic or equational division)

- Meiosis-II is exactly similar to mitosis, so it is also known as meiotic mitosis.
- In this division, two haploid chromosome splits longitudinally and distributed equally to form 4 haploid cells.
- It completes in 4 stages.

1. **Prophase-II**
2. **Metaphase-II**
3. **Anaphase-II**
4. **Telophase-I**I

1. Prophase-II:

- The dyads chromosome becomes thicker and shorter
- Nuclear membrane and nucleolus disappear
- Spindle fibre starts to form

2. Metaphase-II:

- The dyads chromosomes comes to equatorial plane
- Spindle fibres organize between poles and attaches to centromere of chromosome.

3. Anaphase-II:

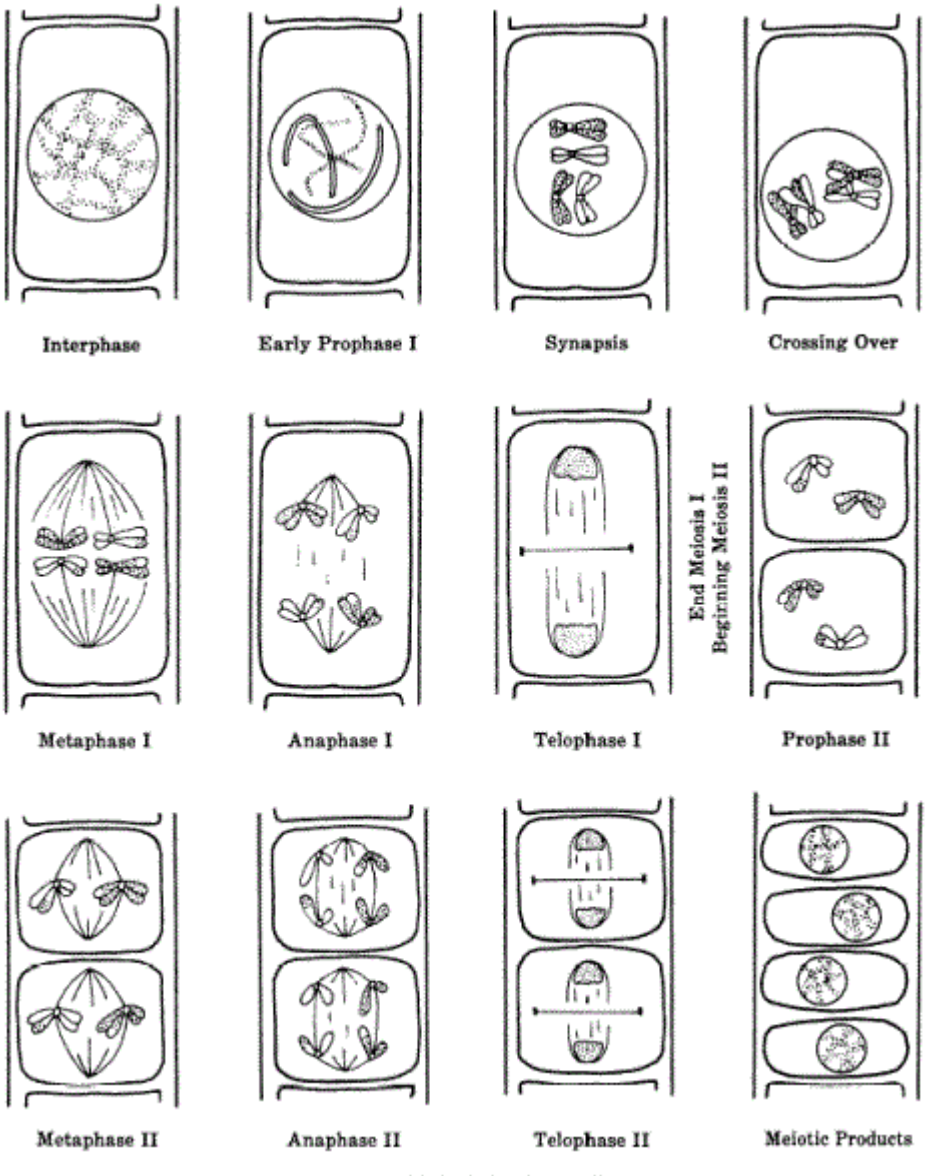
- Centromere of each chromosome divides and sister chromatids separates to form two daughter chromosome
- Spindle fibre contracts and pull the daughter chromosome apart towards opposite pole.

4. Telophase-II:

- Chromosome become organize at respective pole into nuclei
- Chromosome elongates to form thin networks of chromatin
- Nuclear membrane and nucleolus reappears

Cytokinesis-II:

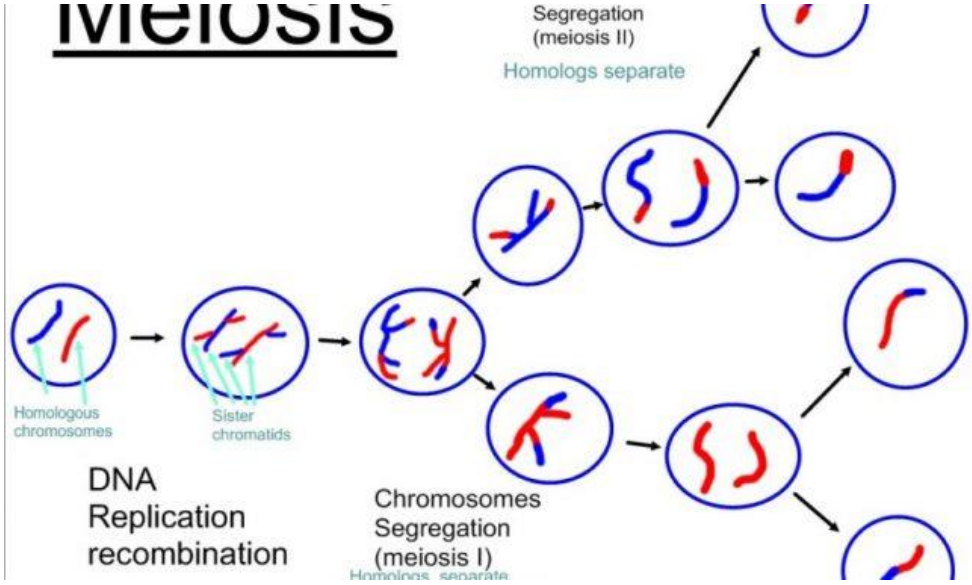
- The result of cytokinesis is four haploid daughter cells (gametes or spores).
- Cytokinesis takes place by cell plate formation in plant cell
- Successive methods: cytokinesis followed by each nuclear division resulting in 4 haploid cells. Eg. Monocot plants
- Simultaneous methods: cytokinesis occurs only after meiosis-II to form 4 haploid cells. Eg. Dicot plants
- In animal cells, cytokinesis occurs by furrow formation or depression.



Meiosis in plant cells.

SIGNIFICANCE OF MEIOSIS

1. Meiosis helps to maintain a constant number of chromosomes by reducing the chromosome number in the gametes
2. Essential for sexual reproduction in higher animals and plants
3. Meiosis helps in the formation haploid gametes and spores for sexual reproduction.
4. Number of chromosome remain fixed in a species from generation to generation
5. Crossing over occurring brings genetic variations in offspring which helps in evolution of organisms.
6. Failure disjunction in Meiosis leads mutation to the formation of polypoid forms.
7. The random distribution of maternal and paternal chromosomes takes place into daughter cells during meiosis and it is a sort of independent assortment which leads to variation.



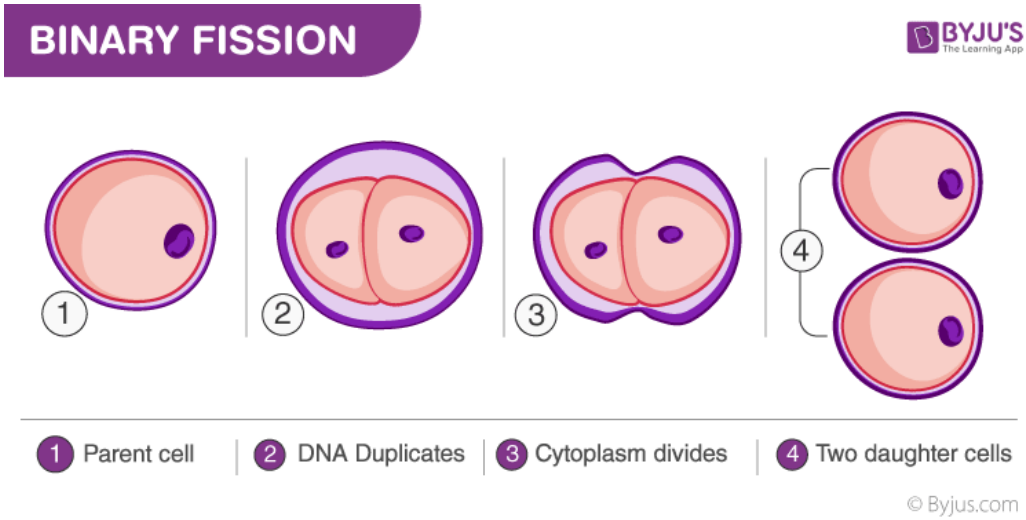
BINARY FISSION

Binary fission is a type of asexual reproduction most commonly seen in prokaryotes and some single-celled eukaryotes. In this method of asexual reproduction, there is a separation of the parent cell into two new daughter cells. This process happens with the duplication and division of the parent's genetic material into two parts, where, each daughter cells receive one copy of its parent DNA.

It is a primary method of reproduction in prokaryotic organisms. Binary Fission occurs without any spindle apparatus formation in the cell. In this process, the single DNA molecule begins replication and then attaches each copy to various parts of the cell membrane. When the cell starts to get pulled apart, the original and replicated chromosomes get separated.

However, asexual mode of reproduction has a significant drawback. All resultant cells are genetically identical mirror copies of each other and the parent cell. Most antibiotics work on this principle. If a parent cell is vulnerable to an antibiotic, then all resultant daughter cells are also vulnerable too. If a mutation occurs in their genes, then it can render a particular strain resistant to antibiotics.

Prokaryotes such as E. coli, Archaea as well as eukaryotes such as euglena reproduce through binary fission.



Binary fission is a form of cell division in eukaryotes. In prokaryotes, it is a form of asexual reproduction

Binary Fission in Bacteria

The process of binary fission is usually rapid, and its speed varies among species. The time required by bacteria to double the number of cells it has is called doubling time. Furthermore, each species requires specific conditions for its growth. These conditions include pH levels, temperature, oxygen, light, moisture, osmotic pressure.

For instance, mesophiles thrive at moderate temperatures ranging from 20°C to 45 °C. The ambient temperature of the human body is 37 °C, which means many of the disease-causing bacteria are mesophiles. *Mycobacterium tuberculosis* is the bacterium that causes tuberculosis in humans. It divides every 15 to 20 hours, which is very slow when compared to other pathogenic bacteria such as Escherichia coli, which can divide every 20 minutes.

On the other end of the spectrum are the extremophiles. These bacteria can survive extremely harsh conditions such as high temperatures, high salinity, highly acidic environments and more. For instance, the *Deinococcus radiodurans* is an extremophilic bacteria that can survive a thousand times more radiation than a person can. Under normal circumstances, it can divide every 48 hours. However, when exposed to harsh conditions like drought, it can slow down its growth rate until more favourable conditions arise.

Read more: Bacteria

The steps involved in the bacterial binary fission are:

Step 1- Replication of DNA

The bacterium uncoils and replicates its chromosome, essentially doubling its content.

Step 2- Growth of a Cell

After copying the chromosome, the bacterium starts to grow larger in preparation for binary fissions. It is followed by an increase in cytoplasm volume as well as an increase in the number of organelles. Another prominent trait of this stage is that the two strands migrate to opposite poles of the cell.

Step 3-Segregation of DNA

The cell elongates with a septum forming at the middle. The two chromosomes are also separated in this phase.

Step 4- Splitting of Cells

A new cell wall is formed at this phase, and the cell splits at the centre, dividing the parent cell into two new daughter cells. Each of the daughter cells contains a copy of the nuclear materials as necessary organelles.

Amoeba Reproduction-Binary Fission in Amoeba

Amoeba is a unicellular organism, and just like bacteria, it reproduces through binary fission. After replicating its genetic material through mitotic division, the cell divides into two equal-sized daughter cells. In this method, two similar individuals are produced from a single parent cell. An amoeba that is about to undergo division grows larger, and eventually, its nucleus extends and divides into two. The division of cytoplasm follows the division of the nucleus. So, two amoebae are produced from a single parent, and the parent's identity is technically "lost."

1. How does Amoeba reproduce?

Amoeba reproduces asexually through binary fission. In this process, an individual divides itself into two daughter cells. These are genetically identical to each other.

2. List out the similarities and differences between binary fission and mitosis

Similarities:

-
- During binary fission as well as mitosis, chromosomes are copied before a cell divides and forms two new daughter cells.

Differences:

- Mitosis is a process of cell division, observed in all eukaryotes -organisms with a true nucleus.
  Binary fission is a process of asexual reproduction carried out by all prokaryotes-organisms without a true nucleus.

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SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOTECHNOLOGY

UNIT – II – CELL BIOLOGY – SBB1101

SBB1101	CELL BIOLOGY	L	T	P	Credits	Total Marks
		3	1	0	4	100

COURSE OBJECTIVES

- Cell biology is the study of the structure and function of prokaryotic and eukaryotic cells. In this course the students will learn different areas of cellular biology including the structure and functions of cell, its organelles, synthesis and function of macromolecules such as carbohydrate, protein, lipid, DNA & RNA; membrane structure and function; bioenergetics; cellular communication; and microscopic techniques to understand the cell structure.

UNIT 1 FUNDAMENTALS OF CELL STRUCTURE **12 Hrs.**

Discovery of cells; Basic properties of cells; Different classes of cells – Prokaryotic and eukaryotic cells. Cell division: Cell cycle; mitosis; meiosis, binary fission.

UNIT 2 CELLULAR MEMBRANES AND MATRICES **12 Hrs.**

Chemical composition and fluidity of membranes; dynamic nature of membranes; transportation across cell membrane; membrane potentials; extracellular matrices – structure and function; cytoskeleton – structure and function.

UNIT 3 CELLULAR ORGANELLES IN ENERGY METABOLISM **12 Hrs.**

Mitochondria – structure and function; Chloroplast – structure and function. Structure of nucleus – nuclear membrane, nucleolus, chromatin, structure of nucleic acids

UNIT 4 CELLULAR ORGANELLES IN METABOLISM **12 Hrs.**

Endoplasmic reticulum – smooth & rough; function of endoplasmic reticulum; Golgi complex – structure and function; Ribosomes – Types, structure and function; Morphology and functions of peroxisomes and glyoxisomes; Plant cell vacuoles.

UNIT 5 TRANSPORT ACROSS CELL MEMBRANE **12 Hrs.**

Passive and active transports, Permeases, Sodium -potassium pumps, Ca 2+ ATPase pump, ATP dependant proton pumps, co-transport, symport, antiport, Endocytosis and Exocytosis. Introduction to intra and extra cellular products of medicinal use.

Max Hours.60

Text Books

1. Freifelder D. 1985. Molecular Biology, Narosa Publishing House. New Delhi.
2. Lewin B. 2007. Genes IX. Oxford University Press, London.
3. Ajoy Paul. 2011. Textbook of Cell and Molecular Biology. Books and Allied Ltd.
4. Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. 2008. Molecular Biology of Cell. 6th Edition. Garland Science, Taylor & Francis group Publishers.
5. Harvey Lodish, Arnold Berk, S Lawrence Zipursky, Paul Matsudaira, David Baltimore, and James Darnell. 1995. Molecular Cell Biology. 3rd Edition. W.H. Freeman Publishers.

END SEMESTER EXAMINATION QUESTION PAPER PATTERN

Max. Marks : 100 **Exam Duration : 3 Hrs.**

PART A : 10 questions of 2 marks each - No choice **20 Marks**

PART B : 2 questions from each UNIT of internal choice; each carrying 16 marks **80 Marks**

PlASMAMEMBRANE

Plasma membrane or plasma-lemma is a bio membrane that occurs on the outside of the cytoplasm in both prokaryotes and eukaryotic cells.

It separates the cellular protoplasm from its external environment. Prokaryotic cells do not have internal membranous partitions. The latter occur in eukaryotic cells as covering of several cell organelles like nucleus, mitochondria, plastids, lysosomes, Golgi bodies, peroxisomes, etc.

Bio membranes line the endoplasmic reticulum. They also occur on thylakoids inside plastids or cristae inside the mitochondria. Vacuoles are separated from cytoplasm by a membrane called tonoplast. All bio membranes are dynamic in nature, continually showing changes in their form, size, structure and function. Plasma membrane was discovered by Schwann (1838). It was named as cell membrane by Nageli and Cramer (1855). The membrane was given the name of plasma lemma by Plowe (1931).

Chemical Nature of Membranes:

Chemically a bio membrane consists of lipids (20—40%), proteins (59—75%) and carbohydrates (1—5%). The important lipids of the membrane are phospholipids, sterols (e.g., cholesterol), glycolipids, sphingolipids (e.g., sphingomyelin, cerebrosides).

Carbohydrates present in the membrane are branched or un-branched oligosaccharides, e.g., hexose, fucose, hexoamine, sialic acid, etc. Proteins can be fibrous or globular, structural, carrier, receptor or enzymatic. About 30 kinds of enzymes have been recorded in different bio membranes, e.g. phosphatases, ATP-aseesterases, nucleases, etc.

The lipid molecules are amphiatic or amphipathic, that is, they possess both polar hydro- philic (water loving) and nonpolar hydrophobic (water repelling) ends. The hydrophilic region is in the form of a head while the hydrophobic part contains two tails of fatty acids.

Hydrophobic tails usually occur towards the centre of the membrane. Protein molecules also possess both polar and nonpolar side chains. Usually their polar hydrophilic linkages are towards the outer side. The nonpolar or hydrophobic linkages are either kept folded inside or used to establish connections with hydrophobic part of the lipids. Several types of models have been put forward to explain the structure of a biomembrane. The more important are Lamellar and Mosaic.

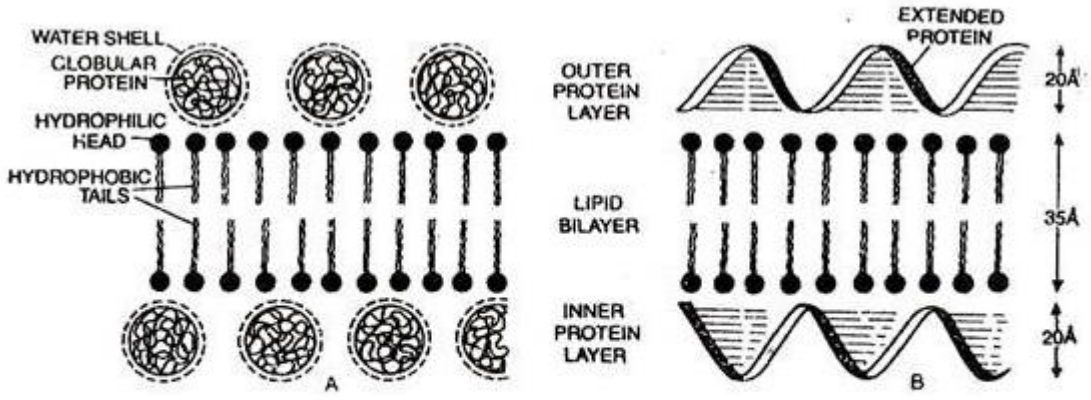
Lamellar Models (= Sandwich Models):

They are the early molecular models of bio membranes. According to these models, bio membranes are believed to have a stable layered structure.

Danielli and Davson Model:

The first lamellar model was proposed by James Danielli and Hugh Davson in 1935 on the basis of their physiological studies. According to Danielli and Davson, a biomembrane contains four molecular layers, two of phospholipids and two of proteins. Phospholipids form a double layer.

The phospholipids bilayer is covered on either side by a layer of hydrated globular or a-protein molecules. The hydrophilic polar heads of the phospholipid molecules are directed towards the proteins. The two are held together by electrostatic forces. The hydrophobic nonpolar tails of the two lipid layers are directed towards the centre where they are held together by hydrophobic bonds and van der Waals forces.



Lamellar models of plasma membrane. (A) after Danielli and Davson (1935). (B) unit membrane, after Robertson (1959).

Robertson Model:

J. David Robertson (1959) modified the model of Danielli and Davson by proposing that the lipid bilayer is covered on the two surfaces by extended or 3-protein molecules. A difference in the proteins of the outer and inner layers was also proposed, e.g., mucoprotin on the outer side and non-mucoid protein on the inner side.

Robertson worked on the plasma membrane of red blood cells under electron microscope. He gave the concept of unit membrane which means that:

(i) All cytoplasmic membranes have a similar structure of three layers with an electron transparent phospholipid bilayer being sand-witched between two electrons dense layers of proteins,

(ii) All bio membranes are either made of a unit membrane or a multiple of unit membrane. The unit membrane of Robertson is also called trailaminar membrane. It has a thickness of about 75 Å with a central lipid layer of 35 A thick and two peripheral protein layers of 20Aeach. According to Robertson, if a membrane contains more than three layers, or is thicker than 75A, it must be a multiple of unit membrane.

Mosaic Model:

Fluid-Mosaic Model. It is the most recent model of a bio membrane proposed by Singer and Nicolson in 1972.

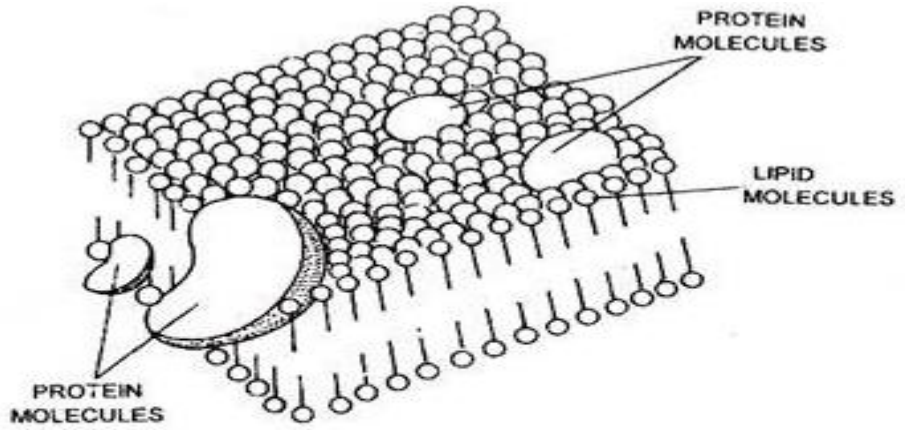
1. According to this model, the membrane does not have a uniform disposition of lipids and proteins but is instead a mosaic of the two. Further, the membrane is not solid but is quasi-fluid.

2. It postulates that the lipid molecules are present in a viscous bilayer as in lamellar model. Protein molecules occur at places both inside and on the outer side of lipid bilayer. The internal proteins are called intrinsic or integral proteins while the external ones are known as extrinsic or peripheral proteins.

The integral or intrinsic proteins account for 70% of the total membrane proteins and pass into the lipid bilayer to different depths. Some of them run throughout the lipid bilayer. They are called tunnel proteins which individually or in a group form channels for the passage of water and water soluble substances.

3. The proteins provide the structural and functional specificity to the membranes. Further since the lipid bilayer is quasifluid, the membrane proteins may shift laterally and thence provide flexibility and dynamism to the membrane.

Many membrane proteins function as enzymes, some of them behave as per-meases for facilitated diffusion and a few proteins act as carriers because they actively transport different substances across the membrane. Certain other protein functions as receptors for hormones, recognition centres and antigens. Some of the lipid at the outer surface is complexed with carbo hydrates to form glycolipids or glycocalyx.



FLUID-MOSAIC MODEL

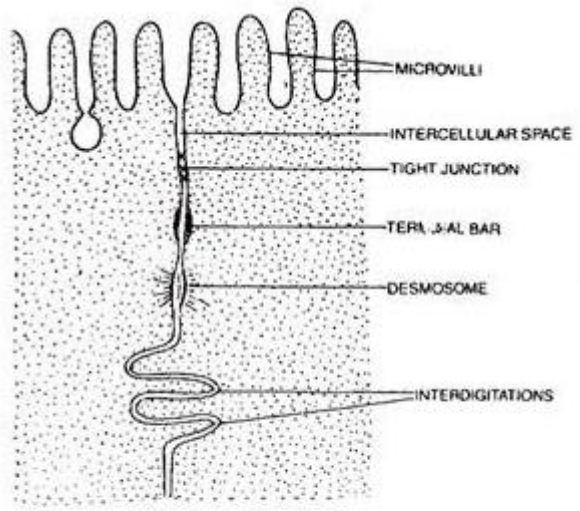
The fluid-mosaic model of unit membrane (note that in this model, protein molecules are embedded within the lipid bilayer).

Modifications of Cell Membrane:

1. Microvilli:

They are finger like evaginations of 0.6—0.8 µm length and 0.1 µm diameter which are found on the free surface of cells engaged in absorption, e.g. intestinal cells, hepatic cells, mesothelial cells, uriniferous tubules. The surface having microvilli is called striated border or brush border.

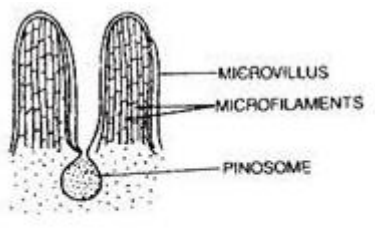
Microvilli increase the surface area several times. They are supported by a web of microfilaments, actin along with myosin, tropomysoin, spectrin, etc. The narrow spaces in between microvilli take part in pinocytosis.



Various modifications of cell membrane.

2. Mesosomes:

They are plasmalemmainfoldings found in bacteria. One type of mesosome is attached internally to the nucleoid. It is required for nucleoid replication and cell division.



Two microvilli and a pinosome developing in between.

3. Junctional Complexes:

They are contacts between adjacent cells which in case of animal cells are separated by spaces of 150-200 Å filled with tissue fluid. The important ones are:

(i) Interdigitations:

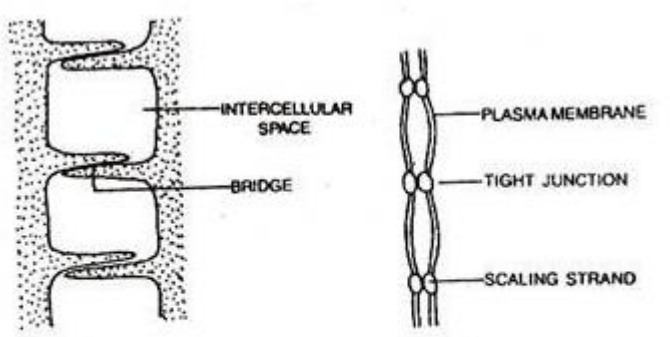
There is interlocking of finger-like membrane outgrowths between two adjacent cells. Interdigitations increase the area of the contact between two cells for exchange of materials.

(ii) Intercellular Bridges:

Projections fro m adjacent cells make contact for rapid conduction of stimuli.

(iii) Tight junctions:

(Zonulae Occludentes, singular— Zonula Occludens). Here plasma membranes of two adjacent cells are fused at a series of points with a network of ridges or sealing strands. Tight junctions occur in epithelia with high electrical resistance and where filtration is to occur through the cells, e.g., capillaries, brain cells, collecting tubules of kidneys.

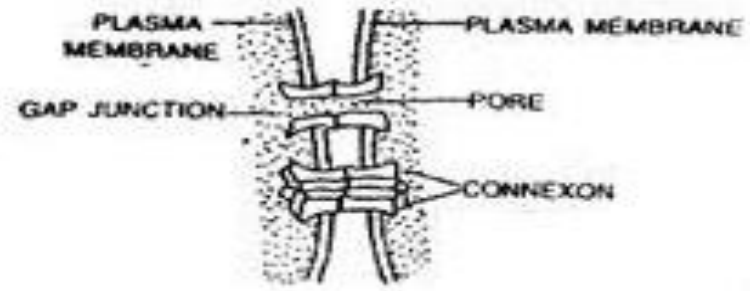


Intercellular bridges.

Tight junctions between two plasma membranes.

(iv) Gap Junctions:

The adjacent cells have protoplasmic connections through special protein cylinders called connexons. Each connexon is made of six identical protein subunits around a hydrophilic channel.



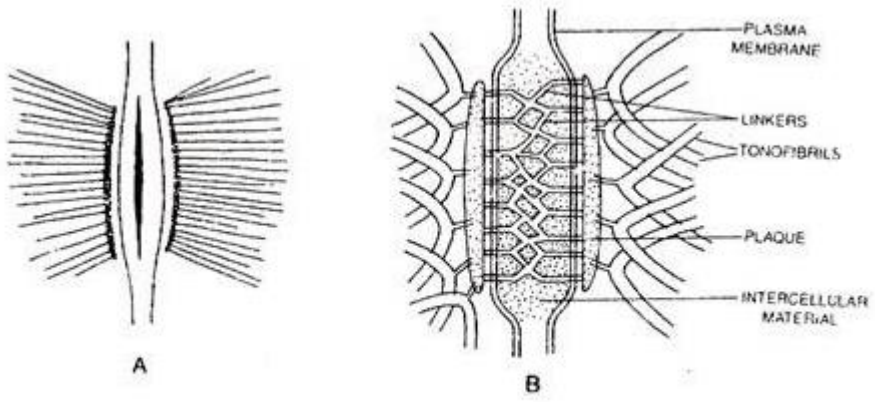
Gap junctions between two cells.

(v) Plasmodesmata:

They are protoplasmic bridges amongst plant cells which occur in the areas of cell wall pits or pores.

(vi) Desmosomes:

(Maculae Adherentes, singular—Macula Adherens). Adjacent membranes possess disc-shaped thickenings of about 0.5 (am diameter, a number of tonofibrils (= tonofilaments) and trans-membrane linkers embedded in dense intercellular material. Desmosomes function as spot welds and are hence called spot desmosomes. They occur in epithelia subjected to disruption.



Structure of desmosome. (A) in section. (B) detailed reconstruction.

(vii) Terminal Bars:

(Belt Desmosomes, Zonulae Adherentes, singular—Zonula Adherens. Intermediary Junction). Terminal bars are desmosomes without tonofibrils. Bands of thickenings occur on the inner surface of membrane. The bands contain microfilaments and intermediate filaments.

Functions of Cell Membranes:

1. The major function of cellular membranes is compartmentalisation. As plasma membranes they separate the cells from their external environment. As organelle coverings, they allow the cell organelles to maintain their identity, specific internal environment and functional individuality.

2. The membranes allow the flow of materials and information between different organelles of the same cell as well as between one cell and another.

3. As plasmodesmata and gap junctions, the bio membranes provide organic connections between adjacent cells.

4. Plasma membranes as well as other membranes of the organelles have selective permeability, that is, they allow only selected substances to pass inwardly to selected degrees. The membranes are impermeable to others.

5. Bio membranes have the property of retentivity, that is, they do not allow the outward passage of substances already permitted entry.

6. Plasma membrane possesses specific substances at its surface which function as recognition centres and points of attachment.

7. Substances attached to cell membrane determine antigen specificity. Glycophorins present on the surface of erythrocytes function as antigen determinants. Histocompatibility antigens signify whether a foreign cell or tissue should be incorporated or rejected.

8. Cell membrane has receptors for certain hormones. The hormone combines with its particular receptors and either changes membrane permeability or activates enzyme adenylate cyclase to produce cyclic AMP from ATP. cAMP then triggers a set of enzymes to perform a particular function.

9. Membranes have carrier proteins for active transport.

10. Cell membranes contain enzymes for performing certain reaction on their surface, e.g., ATP-ase (for ATP synthesis and release of energy from ATP), phosphatases, esterases etc.

11. Certain cell membranes (e.g. plasma membrane in bacteria, thylakoid membranes of chloroplasts, inner mitochondrial membrane) possess electron transport systems.

12. Membrane infolds are used for bulk intake of materials by endocytosis.

MEMBRANE TRANSPORT

Passage of substances across bio membranes or cell membrane is brought about by the following methods:

A. Transport of Water:

(I) Osmosis:

Osmosis is the diffusion of water or solvent molecules through plasma membrane from low osmotic pressure to high osmotic pressure, i.e., from high water contents to low water content. Plasma membrane acts as a differential membrane permitting the movement of water molecules in and out retaining the metabolites.

B. Transport of Ions and Small Molecules:

(II) Passive Transport:

It is a mode of membrane transport where the cell does not spend any energy nor shows any special activity. The transport is according to concentration gradient. It is of two types, passive diffusion and facilitated diffusion.

(a) Passive Diffusion or Transport across Cell Membranes:

Here the cell membrane plays a passive role in the transport of substances across it. Passive diffusion can occur either through lipid matrix of the membrane or with the help of channels.

(i) Lipid Soluble Substances:

It was found out by Overton (1900) that lipid soluble substances pass rapidly across the cell membrane according to their concentration gradient. Based on this finding, Overton proposed that cell membranes are made of lipids.

(ii) Channel Transport:

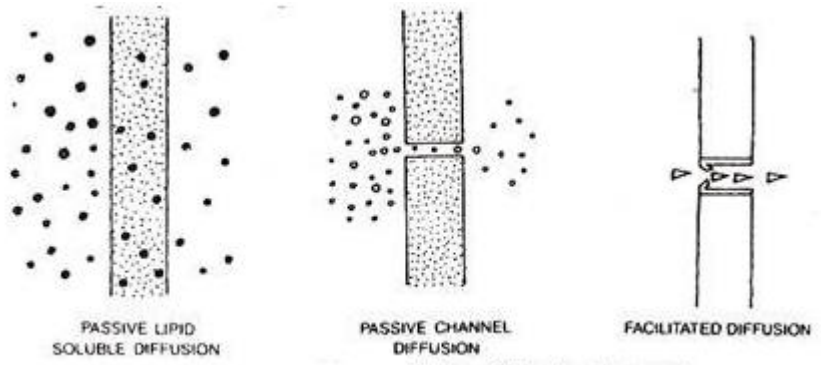
Membrane possesses channels in the form of tunnel proteins which do not carry any charge. They allow water and soluble gases (CO_2 and O_2) to pass according to their concentration gradient. Osmosis is an example of such a transport.

If two solutions of different concentrations are separated by a semi-permeable membrane, the solvent molecules move across the membrane from the less concentrated into the more concentrated solution. This process- the diffusion of solvent molecules into a region in which there is a higher concentration of solute to which the membrane is impermeable, is called osmosis.

Filtration is diffusion under pressure across a membrane having minute pores. Ultra filtration occurs during glomerular filtration inside kidneys. Dialysis is the process of separating small particles (e.g., crystalline solutes) from larger ones (e.g., colloids) due to difference in the rate of diffusion across a membrane having very minute pores.

(b) Facilitated Diffusion:

It occurs through the agency of special membrane proteins called permeases. When such carrier-mediated transport is from an area of greater concentration, energy is not required and the process is called facilitated diffusion. As a result, the rate of transport is stereo-specific.



Modes of Passive Transport.

Entry of glucose into red blood corpuscles is a facilitated diffusion.

The process of facilitated diffusion involves following steps:

1. Diffusing molecules combine with the specific carrier protein molecules forming carrier-protein complexes.

2. The shape of carrier protein molecule changes in response to the diffusing molecule so that the membrane – bound carrier protein complexes form, channels.

3. The shape of carrier protein molecule changes in response to diffusing molecule, allowing the molecule to cross the plasma membrane.

4. Once the diffusing molecule has reached the other side, the change in shape of carrier molecule (conformational change) lowers its affinity with the diffusing molecule, and allows it to be released.

5. After the release of diffusing molecule, the carrier-protein molecule resumes original shape.

The facilitated diffusion enables molecules to cross the otherwise impermeable or poorly permeable membrane.

Facilitated diffusion differs from simple diffusion in following features:

(i) Facilitated diffusion is stereo-specific (either L or D isomer is transported).

(ii) It shows saturation kinetics.

(iii) Facilitated diffusion requires a carrier for transport across the membrane. The carrier protein molecules move to and fro across the membrane by thermal diffusion.

(III) Active Transport:

It is uphill movement of materials across the membranes where the solute particles move against their chemical concentration or electro-chemical gradient. This form of transport requires energy which is provided almost exclusively by hydrolysis of ATP.

Active transport occurs in case of both ions and non-electrolytes, e.g., salt uptake by plant cells, ions, glucose and phenolphthalein in case of renal tubules, sodium and potassium in case of nerve cells, etc. It is supported by various evidences:

(a) Absorption is reduced or stopped with the decrease in oxygen content of the surrounding environment.

(b) Metabolic inhibitors like cyanides inhibit absorption.

(c) Cells often accumulate salts and other substances against their concentration gradient.

(d) Active transport shows saturation kinetics that is, the rate of transport increases with increase in solute concentration till a maximum is achieved. Beyond this value the rate of membrane transport does not increase indicating that it takes place through the agency of special organic molecules called carrier molecules, carrier particles or carrier proteins.

The carrier molecules are ATP ases, enzymes that catalyze the hydrolysis of ATP. The most important of these ATPases is Na^+-K^+ ATP ase which is also known as the Na^+-K^+ pump. There are in addition H^+-K^+ ATPases in the gastric mucosa and the renal tubules.

There is a special carrier molecule for each solute particle. The carrier has its binding site on two surfaces of the membrane. The solute particles combine with the carrier to form carrier-solute complex. In the bound state the carrier undergoes a conformational change which transports the solute to the other side of the membrane. Energy is used in bringing about the conformational change in the carrier. It is provided by ATP. In the process ATP is dephosphorylated to form ADP. Carrier proteins are of three types.

1. Uniport:

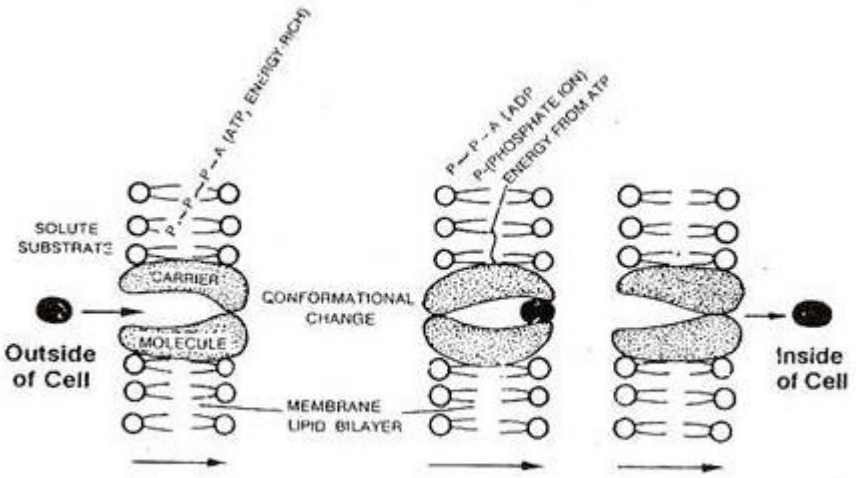
They transport only one substance.

2. Symports:

In some cases, transport requires the binding of more than one substance to the transport protein and the substances are transported across the membrane together. An example is the symport in the intestinal mucosa that is responsible for the co-transport by facilitated diffusion of Na^+ and glucose from the intestinal lumen into mucosal cells.

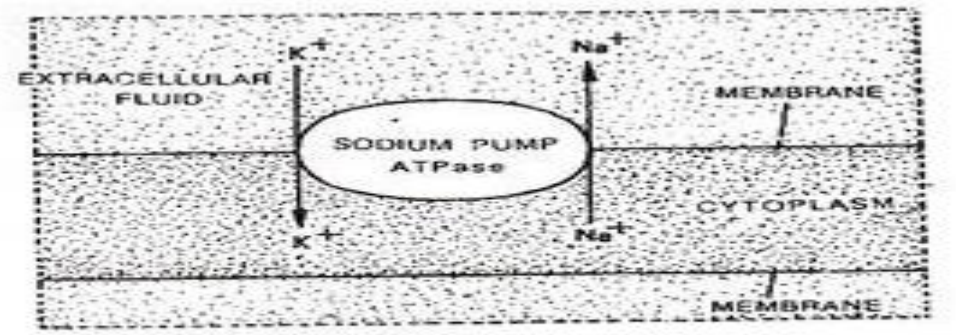
3. Antiports:

They exchange one substance for another. The Na^+-K^+ ATPase is a typical antiport.



Active transport across the membrane through a carrier molecule.

Many animal cells operate a sodium-potassium exchange pump at their plasma membrane. A similar proton pump operates in chloroplasts, mitochondria and bacteria Na^+—K^+ exchange pump operates with the help of enzyme ATP-ase which also functions as a carrier molecule.



Sodium potassium pump.

The enzyme hydrolyses ATP to release energy. The energy is used in bringing about conformational changes in the carrier. For every ATP molecule hydrolysed, three Na^+ ions are pumped outwardly and two K^+ ions are pumped inwardly.

Na^+– K^+ exchange pump performs the following functions: (i) Maintains a positive potential on the outer side of the membrane and relatively electronegative potential on the inner side,

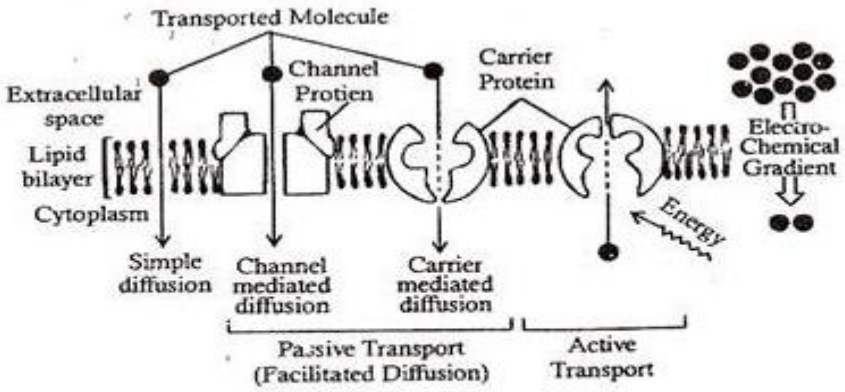
(ii) The pump creates a resting potential in the nerve cells,

(iii) The pump maintains water balance of living cells.

(iv) It helps in urine formation,

(v) It takes part in excretion of salt as in marine animals. Sea gulls and penguins drink sea water. They excrete excess salt through nasal glands. The nasal salt glands have sodium-potassium pump in the plasma membranes of their cells. Na^+ ions are pumped out actively. Chlorine ions pass out passively. Nasal secretion of the two birds possesses 1.5—3.0 times more NaCl concentration than the one present in the blood.

(vi) The unsecreted and unmetabolised excess Na^+ ions present in the extracellular fluid have a tendency to pass back into the cells. Other substances combine with sodium ions and pass inwardly along-with them, e.g., glucose, amino acids in intestine. The phenomenon is called secondary active transport as compared to Na^+—K^+ exchange pump which is called primary active transport.



Different methods of transport of substances through biological membrane. (Simple diffusion, channel mediated diffusion, carrier mediated diffusion and active transport).

Other important pumps include Calcium pump (RBCs, muscles), K^+ pump, CP pump, K^+—H^+ exchange pumps. The last one occurs in guard cells.

Active transport is a means of (i) absorption of most nutrients from the intestine (ii) reabsorption of useful material from the uriniferous tubules (iii) rapid and selective absorption of nutrients by cells (iv) maintaining a membrane potential (v) maintenance of resting potential in nerve cells (vi) maintaining water and ionic balance between cells and extracellular fluid, (vii) excretion of salt glands.

C. Transport of Solid Particles (Bulk transport):

Bulk transport inwards as well as outwards occurs across the plasma membrane by invagination and evagination of the membrane. Bulk transport is useful in carrying large molecules which would

have difficulty in passing through the cell membrane normally. Endocytosis and exocytosis are the two ways in which bulk transport is accomplished.

(IV) Endocytosis is the process of engulfing large sized particles of food substances or of foreign substances. According to the nature of substances, the endocytosis may be:

(i) Pinocytosis or cells drinking is the process of intake of fluid material by the cell.

(ii) Micro pinocytosis is the pinocytosis of subcellular or sub microscopic level.

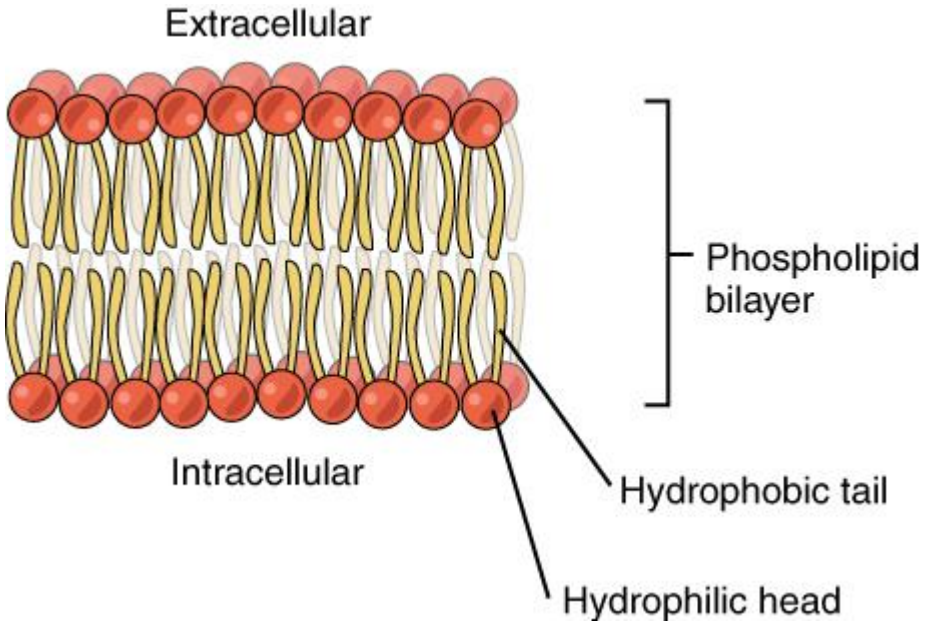
(iii) Rhophaeocytosis is the transfer of small quantities of cytoplasm together with their inclusion.

(iv) Phagocytosis is engulfing of large sized particles of solid food or solid matter by the cell.

(V) Exocytosis is the process of exudating the secretary products to outside the cell cytoplasm. It is also known as emeicytosis or cell vomiting. In cells of pancreas, the vacuoles containing enzymes move from the interior of the cytoplasm towards the surface. Here they fuse with plasma membrane and discharge their contents to the exterior.

CELL MEMBRANE FLUIDITY

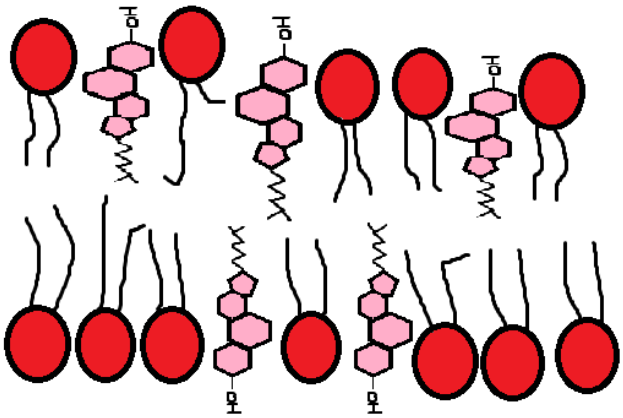
The motion of phospholipid molecules within the lipid bilayer, dependent on the classes of phospholipids present, their fatty acid composition and degree of unsaturation of the acyl chains, the cholesterol concentration, and temperature are called as membrane fluidity



1. If the **length of the phospholipids decreased**, then individually, other molecules within the cell membrane, such as transmembrane proteins, can **move around more easily inside**.

2. **Less Cholesterol**: Heads up! This will **depend on temperature**. More cholesterol in the cell membrane causes the membrane to become more rigid and less permeable to other molecules or ions in *high* temperatures. However, more cholesterol increases fluidity in *low* temperatures. Why? In higher temperatures, phospholipids and other cell membrane molecules are already moving wildly. Cholesterol itself is a chunky lad, so its bulky size will restrict the molecule movement within the membrane more. Thus, in high temperatures, more cholesterol decreases fluidity. However, in low temperatures, this is the opposite case. Imagine in cooler temperatures, the molecules are freezing and pack closer together and thus move less. With the presence of cholesterol, like double bonds and unsaturated fat, the tight packing is inhibited more.
3. **Less Packed Together:**

This is correlated with the double bonds idea. If the molecules, proteins, and individual phospholipids are packed together so closely, this restricts internal molecule movement within the membrane.



Cholesterols, shown as pink molecules in this diagram, take up large spaces in the cell membrane and thus reduce cell membrane fluidity in high temperatures.

Summary of Cell Membrane Fluidity and Factors That Affect Cell Membrane Fluidity

Increase Fluidity	**Decrease Fluidity**
Phospholipids with Shorter Tail Lengths	Phospholipids with Longer Tail Lengths
More Double Bonds (Unsaturated)	Fewer Double Bonds
Less Cholesterol	More Cholesterol (generally in high temperatures)
Less Packed Together	Closer Together/ More Packed together
High Temperature	Low Temperature

Extracellular Matrix

Animal tissue is not only composed of cells but also contains many types of extracellular space or intercellular space. These spaces are again filled up by many types of macromolecules constituting the extracellular matrix.

The extracellular matrix has some specialised functions such as, strength, filtration, adhesion etc. The macromolecules that constitute the extracellular matrix are mainly secreted locally by the cells. In most of the connective tissues the macromolecules are secreted by fibroblast (Fig. 4.9). In some

specialised connective tissues, such as cartilage and bone, they are secreted by chondroblasts and

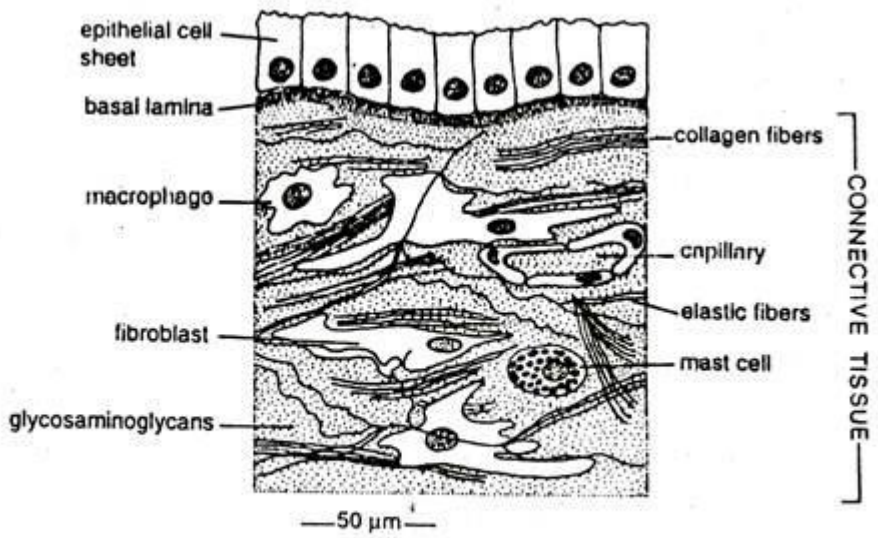


Fig. 4.9: The connective tissue underlying an epithelial cell sheet.

osteoblasts, respectively.

Types of Extracellular Matrix:

The extracellular matrix is made of three main types of extracellular macromolecules:

(i) Polysaccharide glycosaminoglycan's (commonly known as mucopolysaccharides) or GAGs which are usually linked covalently to proteins in the form of proteoglycans;

(ii) **Fibrous proteins of two functional types:**

(a) Mainly structural (e.g., collagen and elastin) and

(b) Mainly adhesive (e.g., fibronectin and laminin);

(iii) Specialised extracellular matrix or basal lamina.

(i) Glycosaminoglycan:

It is a long, un-branched linear polysaccharide chains and consists of repeating disaccharide units in which one of two sugars is always either N-acetyl glucosamine or N-acetylgalactosamine. Hence it is named glycosaminoglycan.

The second sugar of glycosaminoglycan is a uronic acid. In most of the cases, the amino sugar is sulfated. Due to presence of large numbers of carboxyl and sulfate group on most of their sugar residues, glycosaminoglycan's are highly acidic and negatively charged.

There are four main classes of glycosaminoglycan's:

(i) Hyaluronic acid,

(ii) Chondroitin sulfate and dermatan sulfate,

(iii) Heparan sulfate and heparin, and

(iv) Keratan sulfate.

These can be distinguished on the basis of sugar residue, the type of linkage and number and location of sulfate groups (Table 4.1). These are distributed in the extracellular matrix of different tissues. The amount of glycosaminoglycan is usually less than 10% by the weight of the amount of the fibrous proteins.

Hyaluronic acid consisting of several thousand simple sugar residues, is made for regular repeating sequence of non-sulphated disaccharide units. Each unit contains glucuronic acid and N-acetyl glucosamine. Hyaluronic acid is thought to facilitate cell migration during tissue morphogenesis and wound repair.

It is also an important constituent of joint fluid where it serves as a lubricant. It is also evident that excess hyaluronic acid is degraded by the enzyme hyaluronidase.

In most cases, glycosaminoglycan's exist in combination with proteins, the complex being termed a proteoglycans. It is made of core protein linked with numerous un-branched glycosaminoglycan's. A serine residue of the polypeptide chain of core protein is first linked with three sugar residues such as xylose, galactose, galactose (known as link trisaccharide) which, in turn, are attached with glycosamino-glycan.

A proteoglycan aggregate from fetal bovine cartilage is made of 100 proteoglycan monomers which are non-covalently bound to a single hyaluronic acid chain through two link proteins that bind to both the core protein of the proteoglycan and to the hyaluronic acid chain.

Individual proteoglycan monomers consist of a central core protein to which large number of the sulfated glycosaminoglycan's chondroitin sulfate and keratan sulphate are attached.

(ii) Fibrous Protein:

A. Structural Fibrous Protein:

(a) Collagen:

The major fibre-forming structural proteins of the extracellular matrix are collagens. The fibrillar collagens are generally rope-like, triple- stranded helical molecules that aggregate into long cable-like fibrils in the extracellular space.

It is a hydrophobic protein. This protein is found in all multicellular animals and is secreted mainly by connective tissue cells. The basic molecular unit of collagen is tropocollagen or pro-collagen which is 300 nm in length and 1.5 nm wide. It is made of three polypeptide chains that are coiled together to form a triple helical structure.

The major portion of three polypeptide chains of tropocollagen called a-chain (about 1.000 amino acid long) has an a-helix organisation with short non-helical segments of 16-25 residues at both ends that are called tclopeptides.

The amino acid composition of the polypeptide chain of collagen is very simple; they have a large amount of proline and many of the proline and lysine residues are hydroxylated. So far, about 20 distinct a-chains of collagen have been identified. These are encoded by separate genes.

Different combination, and permutations of these genes are expressed in different tissues. So, various combinations of the 20 types of a-chain will theoretically constitute more than thousand types of collagen molecules.

So far, about five isotypes of collagen based on slight differences (Table 4.2) in the organisation of the polypeptide and association with other molecules—such as polysaccharide and glycoprotein—have been found.

These are types I, II, III, IV, and V. Types I, II, III, and V are fibrillar collagens, while type IV is non-fibrillar and assemble into a sheet-like meshwork that constitutes a major part of all basal laminae along with fibronectin and laminin.

(b) Elastin:

Elastin is a fibrillar cross-linked, random-coil, hydrophobic, non-glycosylated protein that gives the elasticity of the tissues—such as skin, blood vessels and lungs—in order to function. This protein is rich in proline and glycine and contains little amount of hydroxyproline and hydroxyserine.

It is secreted into the extracellular space and forms an extensive cross-linked network of fibres and sheets that can stretch and recoil like a rubber band and imparts the elasticity to the extracellular matrix. Elastin fibre also contains a glycoprotein which is distributed as micro-fibrils on the elastin fibre surface.

B. Adhesive Fibrous Protein:

The extracellular matrix contains several adhesive fibrous glycoproteins that bind to both cells and other matrix macromolecules and, ultimately, help cells stick to the extracellular matrix. Fibronectin and laminin are the examples of best characterised large adhesive glycoproteins in the extracellular matrix.

(a) Fibronectin:

Fibronectin is a glycoprotein. It is made of two polypeptide chains which are similar but not identical. The two polypeptides are joined by two disulfide bonds near the carboxyl terminus. Each chain is folded into a series of globular domains joined by a flexible polypeptide segments (Fig. 4.14).

Individual domains are specialised for binding to a particular molecule or to a cell. For example, one domain binds to collagen, another to heparin, another to specific receptors on the surface of various types of cells, and so on. In this way fibronectin builds up the close organisation of the matrix and help cells attach to it.

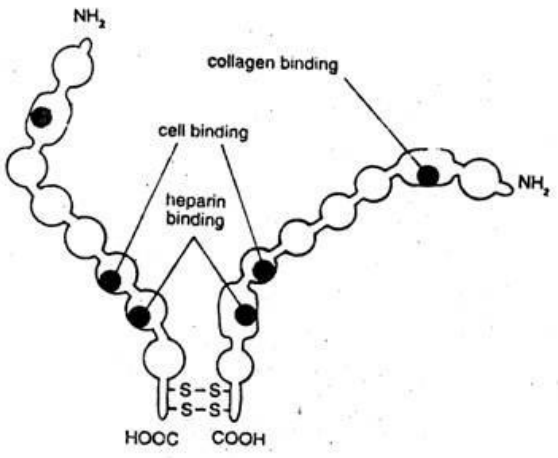


Fig. 4.14: The structure of a fibronectin dimer.

Fibronectin occurs in three forms:

1. A Soluble Dineric Form:

Called plasma fibronectin—which circulates in the blood and other body fluid. The main function of this fibronectin is to enhance blood clotting, wound healing and phagocytosis.

2. Oligomers of Fibronectin:

Called cell-surface fibronectin—which are occasionally found to attach on the cell surface and helps cell to cell attachment.

3. Highly Insoluble Fibrillar Fibronectin:

Called matrix fibronectin—which help cell adhere to the matrix.

(b) Lamina:

Laminin is an adhesive glycoprotein. It is secreted specially by epithelial cells. This protein is a major part of all basal laminae. It binds the epithelial cells to type IV collagen of basal Lamina. Laminin is composed of three multi-domain polypeptide chains, such as A chain, B_1 chain and B_2 chain (Fig. 4.15).

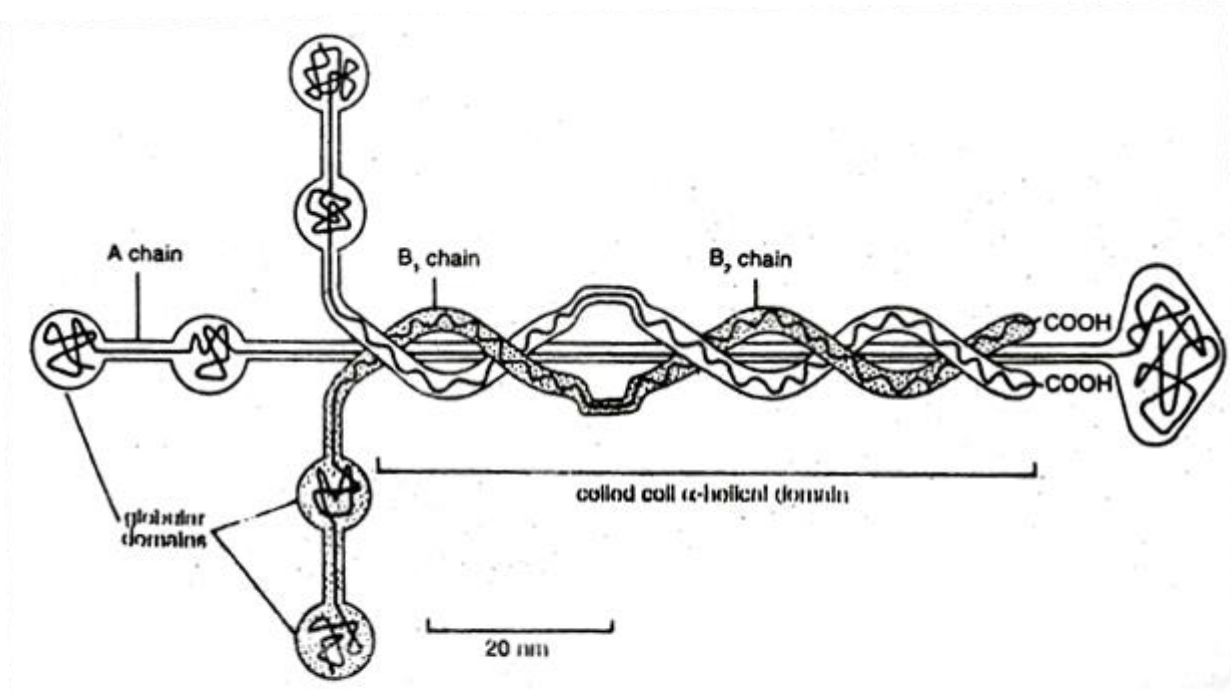


Fig. 4.15: A schematic drawing of a model for the structure of laminin, composed of three polypeptides (A, B_1 and B_2) that are disulfide bonded into an asymmetric cross-like structure.

Laminin is the first extracellular matrix protein to appear in the embryo. In the kidney it acts a major barrier to filtration. When this protein deposits in the glomerular basement membrane, antibodies are produced against laminin and severely affect the kidney functions. Laminin is increased in basement membranes of diabetic patients. Antibodies are also found in Chagas disease.

(iii) Specialised Extracellular Matrix Basal Laminae:

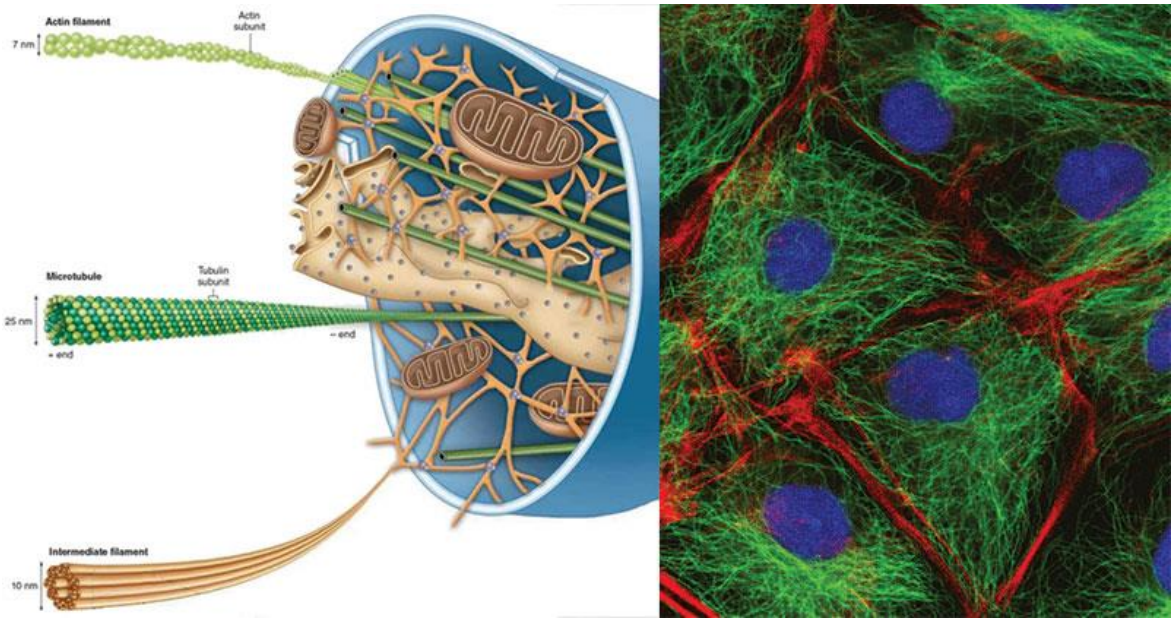
Basal lamina is a continuous thin mat or sheet like specialised extracellular structure that underlies all epithelial cells. Individual muscle cells, fat cells, Schwann cells are wrapped by basal lamina. It is actually linked to the plasma membranes of different types of cell by specific receptors.

The basal lamina separate these cells from the connective tissue. In the glomerulus of the kidney, the basal lamina lie between two cell sheets and forms a porous filter that allows water, ions and small molecules in blood to cross into the urinary space while retaining protein and cells in the blood.

Basal lamina is also able to determine cell polarity, influence cell metabolism, organise the proteins in neighbouring plasma membrane, induces cell differentiation and also facilitate cell migration.

Cytoskeleton

- The cytosol of cells contains fibers that help to maintain cell shape and mobility and that probably provide anchoring points for the other cellular structures.
- Collectively, these fibers are termed as the cytoskeleton.
- The cytoskeleton gives cells structure and shape and allows them to move around. It's also important for intracellular transport.
- At least three general classes of such fibers have been identified in eukaryotic cells. Each of these filaments is a polymer.
- All three filament systems are highly dynamic, altering their organization in response to the needs of the cell.



A. Microtubules

- The thickest are the microtubules (20 nm in diameter) which consist primarily of the tubulin protein.
- Each tubulin subunit is made up of one alpha and one beta-tubulin that are attached to each other, so technically tubulin is a heterodimer, not a monomer. Since it looks like a tube, it is named as microtubule.
- In a microtubule structure, tubulin monomers are linked both at their ends and along their sides (laterally). This means that microtubules are quite stable along their lengths.
- Since the tubulin subunits are always linked in the same direction, microtubules have two distinct ends, called the plus (+) and minus (-) ends.
- On the minus end, alpha-tubulin is exposed, and on the plus end, beta-tubulin is exposed.
- Microtubules preferentially assemble and disassemble at their plus ends.

Functions

1. Transportation of water, ions or small molecules.
2. Cytoplasmic streaming (cyclosis).
3. Formation of fibers or asters of the mitotic or meiotic spindle during cell division.
4. Formation of the structural units of the centrioles, basal granules, cilia, and flagella.

B. Microfilaments

- The thinnest are the microfilaments (7 nm in diameter) which are solid and are principally made of two intertwined strands of a globular protein called actin. For this reason, microfilaments are also known as actin filaments.

- Actin is powered by ATP to assemble its filamentous form, which serves as a track for the movement of a motor protein called myosin.
- This enables actin to engage in cellular events requiring motion such as cell division in animal cells and cytoplasmic streaming, which is the circular movement of the cell cytoplasm in plant cells.

Functions

1. They maintain the shape of the cell.
2. Form contractile component of cells, mainly of the muscle cells.
3. White blood cells can move to the site of an infection and engulf the pathogen due to microfilaments.

C. Intermediate Filaments

- The fibers of the middle-order are called the intermediate filaments (IFs) having a diameter of 10 nm.
- They are composed of a family of related proteins sharing common structural and sequence features.
- They having been classified according to their constituent protein such as desmin filaments, keratin filaments, neurofilaments, vimentin, and glial filaments.

Functions

1. Intermediate filaments contribute to cellular structural elements and are often crucial in holding together tissues like skin.

D. Microtrabecular Lattice

Recently, cytoplasm has been found to be filled with a three-dimensional network of interlinked filaments of cytoskeletal fibers, called a micro-trabecular lattice. Various cellular organelles such as ribosomes, lysosomes, etc., are found anchored to this lattice. The micro-trabecular lattice being flexible changes its shape and results in the change of cell shape during cell movement.

Functions of Cytoskeleton

The cytoskeleton is responsible for lots of important cellular functions:

- In animal cells, which lack a rigid cell wall, it is the cytoskeleton that determines cell shape.
- It allows cells to move.
- Engulf particles.
- Brace themselves against pulling forces.
- Transport vesicles through the cytosol.
- Separate chromosomes during cell division.

- It allows our muscles to contract.

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SCHOOL OF BIO CHEMICAL ENGINEERING

DEPARTMENT OF BIOTECHNOLOGY

UNIT – III – CELL BIOLOGY – SBB1101

SBB1101	CELL BIOLOGY	L	T	P	Credits	Total Marks
		3	1	0	4	100

COURSE OBJECTIVES

- Cell biology is the study of the structure and function of prokaryotic and eukaryotic cells. In this course the students will learn different areas of cellular biology including the structure and functions of cell, its organelles, synthesis and function of macromolecules such as carbohydrate, protein, lipid, DNA & RNA; membrane structure and function; bioenergetics; cellular communication; and microscopic techniques to understand the cell structure.

UNIT 1 FUNDAMENTALS OF CELL STRUCTURE **12 Hrs.**

Discovery of cells; Basic properties of cells; Different classes of cells – Prokaryotic and eukaryotic cells. Cell division: Cell cycle; mitosis; meiosis, binary fission.

UNIT 2 CELLULAR MEMBRANES AND MATRICES **12 Hrs.**

Chemical composition and fluidity of membranes; dynamic nature of membranes; transportation across cell membrane; membrane potentials; extracellular matrices – structure and function; cytoskeleton – structure and function.

UNIT 3 CELLULAR ORGANELLES IN ENERGY METABOLISM **12 Hrs.**

Mitochondria – structure and function; Chloroplast – structure and function. Structure of nucleus – nuclear membrane, nucleolus, chromatin, structure of nucleic acids

UNIT 4 CELLULAR ORGANELLES IN METABOLISM **12 Hrs.**

Endoplasmic reticulum – smooth & rough; function of endoplasmic reticulum; Golgi complex – structure and function; Ribosomes – Types, structure and function; Morphology and functions of peroxisomes and glyoxisomes; Plant cell vacuoles.

UNIT 5 TRANSPORT ACROSS CELL MEMBRANE **12 Hrs.**

Passive and active transports, Permeases, Sodium -potassium pumps, Ca 2+ ATPase pump, ATP dependant proton pumps, co-transport, symport, antiport, Endocytosis and Exocytosis. Introduction to intra and extra cellular products of medicinal use.

Max Hours.60

Text Books

1. Freifelder D. 1985. Molecular Biology, Narosa Publishing House. New Delhi.
2. Lewin B. 2007. Genes IX. Oxford University Press, London.
3. Ajoy Paul. 2011. Textbook of Cell and Molecular Biology. Books and Allied Ltd.
4. Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. 2008. Molecular Biology of Cell. 6th Edition. Garland Science, Taylor & Francis group Publishers.
5. Harvey Lodish, Arnold Berk, S Lawrence Zipursky, Paul Matsudaira, David Baltimore, and James Darnell. 1995. Molecular Cell Biology. 3rd Edition. W.H. Freeman Publishers.

END SEMESTER EXAMINATION QUESTION PAPER PATTERN

Max. Marks : 100 **Exam Duration : 3 Hrs.**

PART A : 10 questions of 2 marks each - No choice **20 Marks**

PART B : 2 questions from each UNIT of internal choice; each carrying 16 marks **80 Marks**

UNIT: 3

CELLULAR ORGANELLES IN ENERGY METABOLISM

Mitochondria-structure and function, Chloroplast- structure and function, Structure of nucleus-nuclear membrane, nucleolus, chromatin, structure of nucleic acids.

MITOCHONDRIA DEFINITION

Mitochondria are oxygen-consuming ribbon-shaped cellular organelles of immense importance floating free throughout the cell.

They are known as the “powerhouse of the cell” since these organelles supply all the necessary biological energy to the cell by oxidizing the substrates available.

The enzymatic oxidation of chemical compounds in the mitochondria releases energy.

Since mitochondria act as the power-houses, they are abundantly found on those sites where energy is earnestly required such as sperm tail, muscle cell, liver cell (up to 1600 mitochondria), microvilli, oocyte (more than 300,000 mitochondria), etc.

Typically, there are about 2000 mitochondria per cell, representing around 25% of the cell volume.

In 1890, mitochondria were first described by Richard Altmann and he called them bioblasts. Benda in the year 1897 coined the term ‘mitochondrion’.

Mitochondria are mobile, plastic organelles that have a double-membrane structure. It ranges from 0.5 to 1.0 micrometer in diameter. It has four distinct domains: the outer membrane, the inner membrane, the intermembrane space, and the matrix.

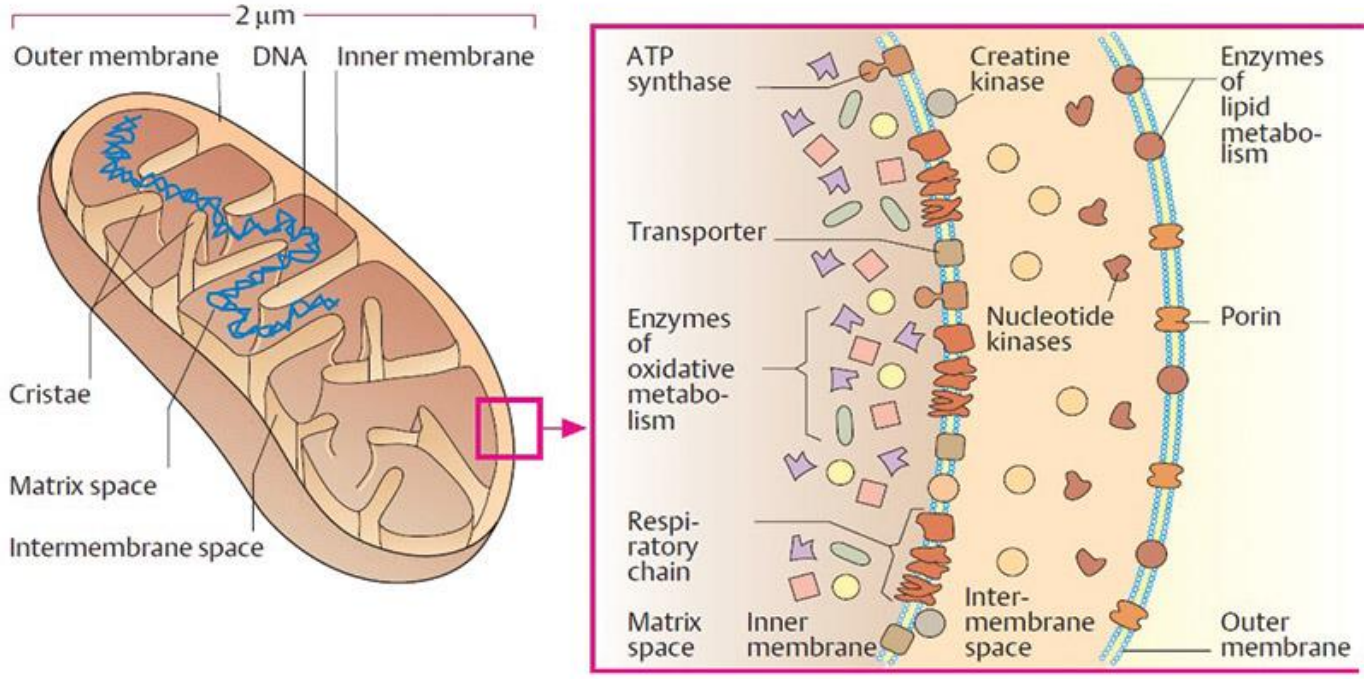


Figure: Structure of Mitochondria

- The organelle is enclosed by two membranes—a smooth outer membrane and a markedly folded or tubular inner mitochondrial membrane, which has a large surface and encloses the matrix space.
- The intermembrane space is located between the inner and outer membranes.
- The number and shape of the mitochondria, as well as the numbers of cristae they have, can differ widely from cell type to cell type.
- Tissues with intensive oxidative metabolism— e. g., heart muscle—have mitochondria with particularly large numbers of cristae.
- Even within one type of tissue, the shape of the mitochondria can vary depending on their functional status.
- Both mitochondrial membranes are very rich in proteins.

Outer Mitochondrial Membrane

- The outer mitochondrial membrane resembles more with the plasma membrane in structure and chemical composition.
- Porins in the outer membrane allow small molecules to be exchanged between the cytoplasm and the intermembrane space.

Inner Mitochondrial Membrane

- The inner mitochondrial membrane is rich in many enzymes, coenzymes, and other components of electron transport chain. It also contains proton pumps and many permease proteins for the transport of various molecules such as citrates, ADP, phosphate, and ATP.
- The inner mitochondrial membrane gives out finger-like outgrowths (cristae) towards the lumen of the mitochondrion and contains tennis-racket shaped F1 particles that contain ATP-ase enzyme for ATP synthesis.
- The inner mitochondrial membrane is completely impermeable even to small molecules (with the exception of O2, CO2, and H2O).
- Numerous transporters in the inner membrane ensure the import and export of important metabolites.

Intermembrane Space

- It is the space between the outer and inner membrane of the mitochondria, it has the same composition as that of the cell's cytoplasm.
- There is a difference in the protein content in the intermembrane space.

Mitochondrial Matrix

- The mitochondrial matrix which is the liquid (colloidal) area encircled by the inner membrane, contains the soluble enzymes of the **Krebs cycle** which completely oxidize the acetyl-CoA to produce CO2, H2O and hydrogen ions. Hydrogen ions reduce the molecules of NAD and FAD, both of which pass on hydrogen ions to respiratory or electron transport chain where oxidative phosphorylation takes place to generate energy-rich ATP molecules.
- Mitochondria also contain in their matrix single or double circular and double-stranded DNA molecules called mt DNA and also the 55S ribosomes, called mitoribosomes. Since mitochondria can synthesize 10 percent of their proteins in their own protein-synthetic machinery, they are considered as **semi-autonomous organelles**.

Functions of Mitochondria

1. The most important function of mitochondria is to produce energy. Mitochondria produce the molecule adenosine triphosphate (ATP), one of the cell's energy currencies that provide the energy to drive a host of cellular reactions and mechanisms.
2. The simpler molecules of nutrition are sent to the mitochondria to be processed and to produce charged molecules. These charged molecules combine with oxygen and produce ATP molecules. This process is known as oxidative phosphorylation.
3. Mitochondria may also produce heat (brown fat), and accumulate iron-containing pigments (Heme ferritin), ions of Ca2+ and HPO_4^{2-} (or phosphate; e.g., osteoblasts of bones or yolk proteins).
4. Mitochondria help the cells to maintain the proper concentration of calcium ions within the compartments of the cell.
5. The mitochondria also help in building certain parts of blood and hormones like testosterone and estrogen.
6. The liver cell's mitochondria have enzymes that detoxify ammonia.
7. The mitochondria also play an important role in the process of apoptosis or programmed cell death.
8. Abnormal death of cells due to the dysfunction of mitochondria can affect the function of an organ.

Mitochondrial Electron Transport Chain

The mitochondrial electron transport chain is composed of three main membrane-associated electron carriers flavoproteins (FMN, FAD), cytochromes, and quinones (coenzyme Q, also known as ubiquinone because it is a ubiquitous quinone in biological systems).

All these electron carriers reside within the inner membrane of the mitochondria and operate together to transfer electrons from donors, like NADH and $FADH_2$, to acceptors, such as O_2. The, electrons flow from carriers with more negative reduction potentials to those with more positive reduction potentials and eventually combine with O_2 and H to form water.

However, the mitochondrial electron transport system is arranged into four enzyme complexes of carriers, each capable of transporting electrons part of the way to O_2 (Fig. 24.5). Coenzyme Q and cytochrome c connect the complexes with each other.

:

The four enzyme complexes of carriers are: NADH-Q oxidoreductase, succinate-Q-reductase, Q-cytochrome c oxidoreductase, and cytochrome c oxidase. These complexes are the enzyme complex and each of them consists of different prosthetic groups (Table 24.2).

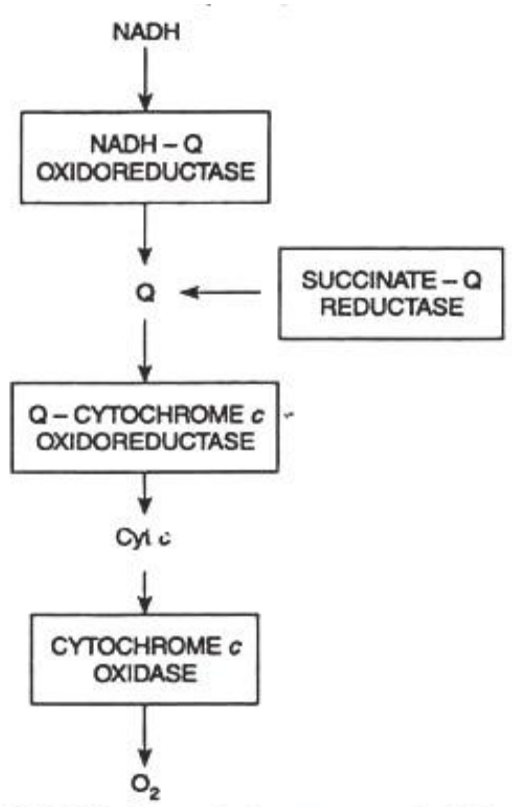


FIG. 24.5. Sequential arrangement of four complexes of electron carriers in mitochondrial electron transport chain.

TABLE 24.2. Four enzyme complexes of mitochondrial electron transport chain

	Enzyme complex	*Mass (KDa)*	*Number of subunits*[1]	*Prosthetic groups*
Complex I :	NADH-Q oxidoreductase (NADH dehydrogenase)	880	42(14)	FMN, FeS
Complex II:	Succinate-Q reductase (succinate dehydrogenase)	140	4	FAD, FeS
Complex III:	Q-cytochrome *c* oxidoreductase	250	10	Cyt b_H (Heme b_H), Cyt b_L (Heme b_L), FeS, Cyt c_1 (Heme c_1)
Complex IV :	Cytochrome *c* oxidase	160	10 (3-4)	Cyt *a* (Heme *a*), Cyt a_3 (Heme a_3), Cu_A, Cu_B

The process of mitochondrial electron transport chain is summarized in Figure 24.6, which shows the flow of electrons and protons through the four enzyme complexes of the transport chain.

The whole process of mitochondrial electron transport can be represented in brief in the following manner:

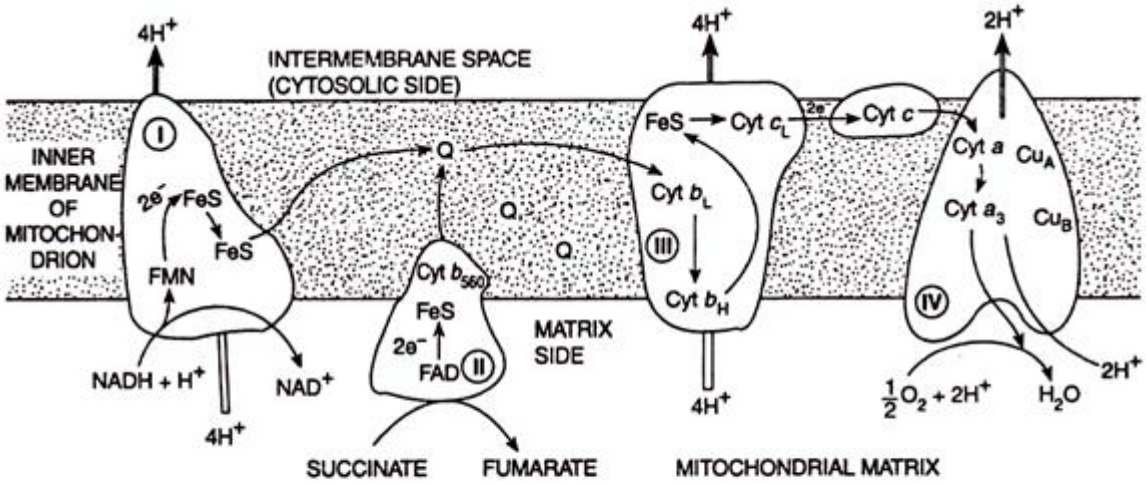


FIG. 24.6. Summary of mitochondrial electron transport chain showing the flow of electrons and protons (H^+) through the four enzyme complexes of the transport chain. Electrons reach quinone (Q) through complexes I and II. Q serves as a mobile carrier of electrons and passes them to complex III, which then passes them to cytochrome *c*, another mobile connecting link. Complex IV then transfers electrons from reduced cytochrome *c* to O_2. Electron flow through complexes I, III and IV is accompanied by proton flow from the mitochondrial matrix to the intermembrane space (cytosolic side)

1. Electrons donated by NADH enter the chain at complex I (NADH-Q-oxidoreductase) and pass through a flavoprotein (FMN) to a series of iron-sulphur-proteins (FeS) and then to ubiquinone (Q).

2. Electrons donated by succinate enter the chain at Complex II (succinate-Q-reductase) and pass through a flavoprotein (FAD) and FeS centres and then to ubiquinone (Q).

3. Ubiquinone (Q) serves as a mobile carrier of electrons received from complexes I and II and passes them to complex III (Q-cytochrome c oxidoreductase).

4. Complex III called Q-cytochrome c oxidoreductase or cytochrome bc_1 complex passes the electrons through its prosthetic groups Cyt b_L (Heme b_L), Cyt b_H (heme b_H), FeS, and Cyt c_L (Heme c_L) to cytochrome c.

5. Cytochrome c (Cyt c), a mobile connecting link between complex III and IV, passes electrons to complex IV (cytochrome c oxidase). The latter carries electrons through its prosthetic groups Cyt a (Heme a), Cyt a_3 (Heme a_3) Cu_A and Cu_B and transfers them to molecular oxygen, reducing it to H_2O.

6. Electron flow through complexes I, III and IV is accompanied by proton flow from the mitochondrial matrix (which becomes negatively charged) to inter membrane space or cytosolic side (which becomes positively charged). The number of protons (H^+) moved across the membrane at each site per pair of electrons transported is still somewhat uncertain; the current consensus is that at least 10 protons move outward during NADH oxidation.

CHLOROPLAST

Plants form the basis of all life on earth and are known as producers. Plant cells contain structures known as plastids which are absent in animal cells. These plastids are double-membraned cell organelles which play a primary role in the manufacturing and storing of food. There are three types of plastids –

- Chromoplasts- They are the colour plastids, found in all flowers, fruits and are mainly responsible for their distinctive colours.
- Chloroplasts- They are green coloured plastids, which comprises of green-coloured pigments within the plant cell and are called as the chlorophyll.
- Leucoplasts- They are colourless plastids and are mainly used for the storage of starch, lipids, and proteins within the plant cell.

Chloroplast Definition

"Chloroplast is an organelle that contains the photosynthetic pigment chlorophyll that captures sunlight and converts it into useful energy, thereby, releasing oxygen from water. "

What is a Chloroplast?

Chloroplasts are found in all green plants and algae. They are the food producers of plants. These are found in the guard cells located in the leaves of the plants. They

contain a high concentration of chlorophyll that traps sunlight. This cell organelle is not present in animal cells.

Chloroplast has its own DNA and can reproduce independently from the rest of the cell. They also produce amino acids and lipids required for the production of chloroplast membrane.

DIAGRAM OF CHLOROPLAST

The chloroplast diagram below represents the chloroplast structure mentioning the different parts of the chloroplast. The parts of a chloroplast such as the inner membrane, outer membrane, intermembrane space, thylakoid membrane, stroma and lamella can be clearly marked out.

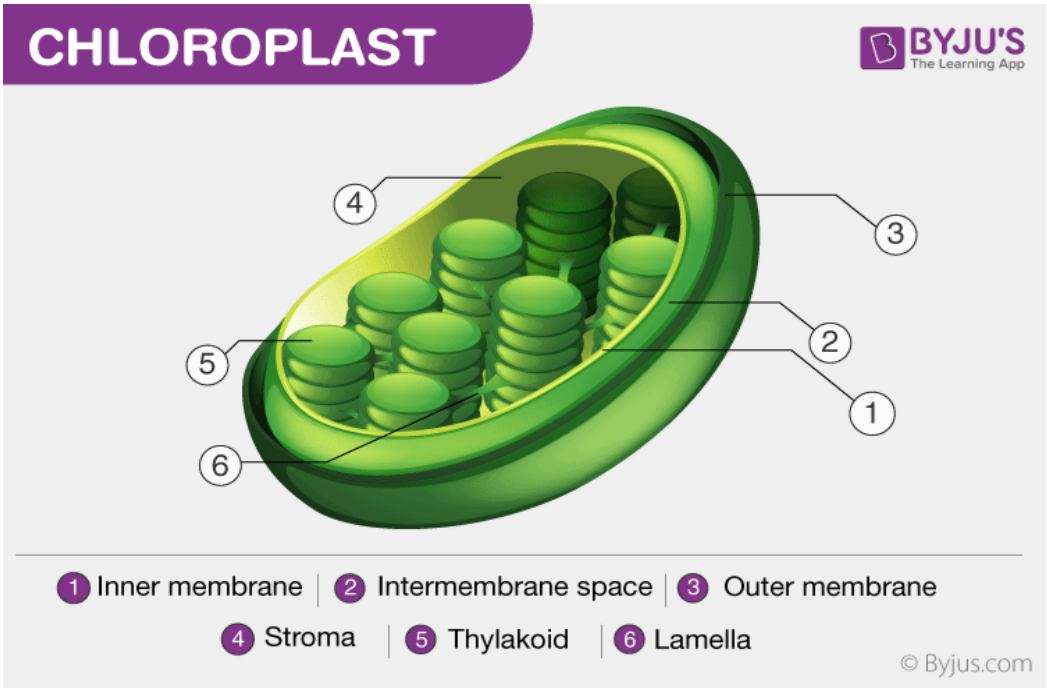


Diagram representing Chloroplast Structure

Chloroplasts are found in all higher plants. It is oval or biconvex, found within the mesophyll of the **plant cell.** The size of the chloroplast usually varies between 4-6 µm in diameter and 1-3 µm in thickness. They are double-membrane organelle with the

presence of outer, inner and the thin intermembrane space. There are two distinct regions present inside a chloroplast known as the grana and stroma.

- Grana is made up of stacks of disc-shaped structures known as thylakoids. The grana of the chloroplast consists of chlorophyll pigments and are the functional units of chloroplasts.
- Stroma is the homogenous matrix which contains grana and is similar to the cytoplasm in cells in which all the organelles are embedded. Stroma also contains various enzymes, DNA, ribosomes, and other substances. Stroma lamellae function by connecting the stacks of thylakoid sacs.

The chloroplast structure consists of the following parts:

Membrane Envelope

It comprises inner and outer lipid bilayer membranes. The inner membrane separates the stroma from the intermembrane space.

Intermembrane Space

The space between inner and outer membranes.

Thylakoid System

The system is suspended in the stroma. It is a collection of membranous sacs called thylakoids. The green coloured pigments called chlorophyll are found in the thylakoid membranes. It is the sight for the process of light-dependent reactions of the photosynthesis process. The thylakoids are arranged in stacks known as grana and each granum contains around 10-20 thylakoids.

Stroma

It is a colourless, alkaline, aqueous, protein-rich fluid present within the inner membrane of the chloroplast present surrounding the grana.

Grana

These are the sites of conversion of light energy into chemical energy.

Chlorophyll

It is a green photosynthetic pigment that helps in the process of photosynthesis.

FUNCTIONS OF CHLOROPLAST

Following are the important chloroplast function:

- The most important function of the chloroplast is to synthesize food by the process of photosynthesis.
- Absorbs light energy and converts it into chemical energy.
- Chloroplast has a structure called chlorophyll which functions by trapping the solar energy and used for the synthesis of food in all green plants.
- Produces NADPH and molecular oxygen(O_2) by photolysis of water.
- Produces ATP – Adenosine triphosphate by the process of photosynthesis .
- The carbon dioxide (CO2) obtained from the air is used to generate carbon and sugar during the Calvin Cycle or dark reaction of photosynthesis.

Photosynthesis

The process by which green plants and some other organisms use sunlight to synthesize nutrients from carbon dioxide and water. Photosynthesis in plants generally involves the green pigment chlorophyll and generates oxygen as a by-product.

Photosynthesis Equation

Photosynthesis reaction involves two reactants, carbon dioxide, and water. These two reactants yield two products, namely, oxygen and glucose. Hence, the photosynthesis reaction is considered to be an endothermic reaction. Following is the photosynthesis formula:

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

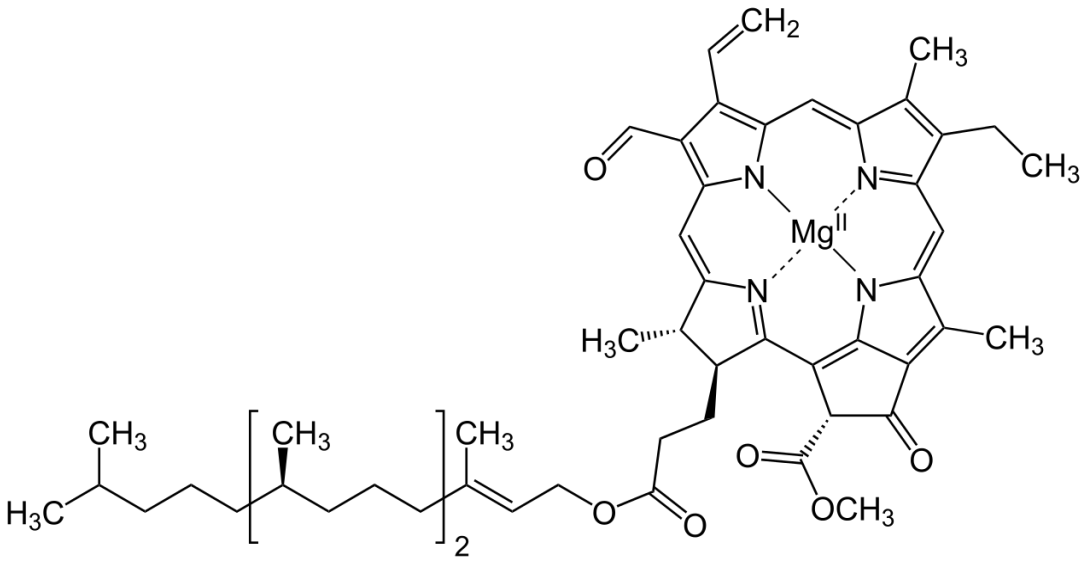
Unlike plants, certain bacteria that perform photosynthesis do not produce oxygen as the by-product of photosynthesis. Such bacteria are called anoxygenic photosynthetic bacteria. The bacteria that do produce oxygen as a by-product of photosynthesis are called oxygenic photosynthetic bacteria.

Photosynthetic Pigments

There are four different types of pigments present in leaves:

1. Chlorophyll a
2. Chlorophyll b
3. Xanthophylls
4. Carotenoids

Structure Of Chlorophyll



The structure of Chlorophyll consists of 4 nitrogen atoms that surround a magnesium atom. A hydrocarbon tail is also present. Pictured above is chlorophyll-*f*, which is more effective in near-infrared light than chlorophyll-*a*

Chlorophyll is a green pigment found in the chloroplasts of the **plant cell** and in the mesosomes of cyanobacteria. This green colour pigment plays a vital role in the process of photosynthesis by permitting plants to absorb energy from sunlight. Chlorophyll is a mixture of chlorophyll-*a* and chlorophyll-*b*.

Besides green plants, other organisms that perform photosynthesis contain various other forms of chlorophyll such as chlorophyll-*c1*, chlorophyll-*c2*, chlorophyll-*d* and chlorophyll-*f*.

Process Of Photosynthesis

At the cellular level, the photosynthesis process takes place in cell organelles called chloroplasts. These organelles contain a green-coloured pigment called chlorophyll, which is responsible for the characteristic green colouration of the leaves.

As already stated, photosynthesis occurs in the leaves and the specialized cell organelles responsible for this process is called the chloroplast. Structurally, a leaf comprises a petiole, epidermis and a lamina. The lamina is used for absorption of sunlight and carbon dioxide during photosynthesis.

"Photosynthesis Steps:"

- During the process of photosynthesis, carbon dioxide enters through the stomata, water is absorbed by the root hairs from the soil and is carried to the leaves through the xylem vessels. Chlorophyll absorbs the light energy from the sun to split water molecules into hydrogen and oxygen.
- The hydrogen from water molecules and carbon dioxide absorbed from the air are used in the production of glucose. Furthermore, oxygen is liberated out into the atmosphere through the leaves as a waste product.
- Glucose is a source of food for plants that provide energy for **growth and development,** while the rest is stored in the roots, leaves, and fruits for their later use.

- Pigments are other fundamental cellular components of photosynthesis. They are the molecules that impart colour and they absorb light at some specific wavelength and reflect back the unabsorbed light. All green plants mainly contain chlorophyll a, chlorophyll b and carotenoids which are present in the thylakoids of chloroplasts. It is primarily used to capture light energy. Chlorophyll-a is the main pigment.

The **process of photosynthesis** occurs in two stages:

- Light-dependent reaction or light reaction
- Light independent reaction or dark reaction

Stages of Photosynthesis in Plants de

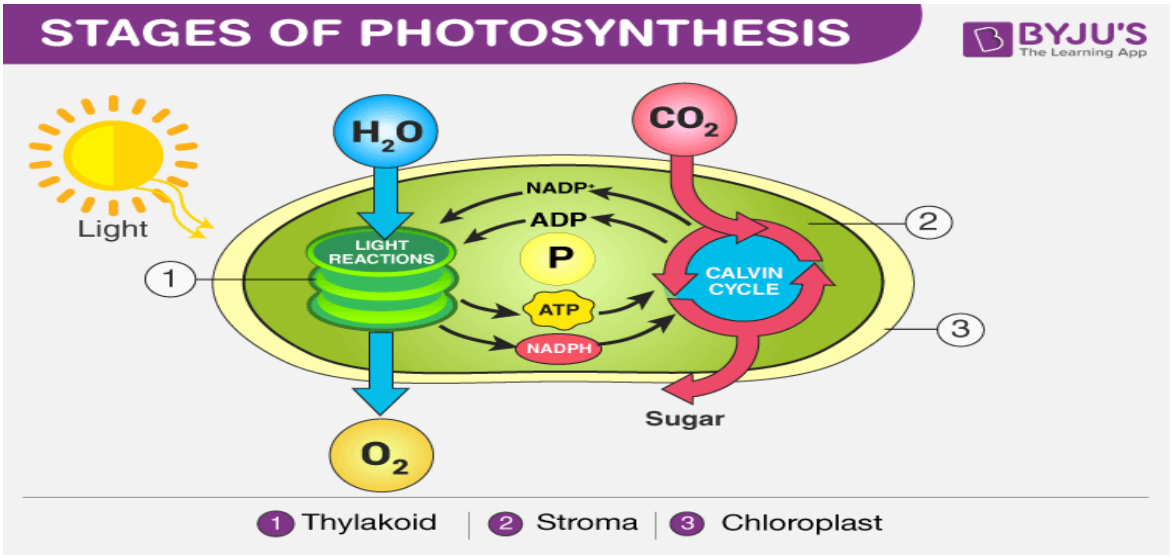


Diagram depicting the two phases – Light reaction and Dark reaction

Light Reaction of Photosynthesis (or) Light-dependent Reaction

- Photosynthesis begins with the light reaction which is carried out only during the day in the presence of sunlight. In plants, the light-dependent reaction takes place in the thylakoid membranes of chloroplasts.
- The Grana, membrane-bound sacs like structures present inside the thylakoid functions by gathering light and is called photosystems.

- These photosystems have large complexes of pigment and proteins molecules present within the plant cells which plays the primary role during the process of light reactions of photosynthesis.
- There are two types of photosystems: photosystem I and photosystem II.
- Under the light-dependent reactions, the light energy is converted to ATP and NADPH which are used in the second phase of photosynthesis.
- During the light reactions, ATP and NADPH are generated by two electron-transport chains, water is used and oxygen is produced.

The chemical equation in the light reaction of photosynthesis can be reduced to:

$2H_2O + 2NADP+ + 3ADP + 3Pi \rightarrow O_2 + 2NADPH + 3ATP$

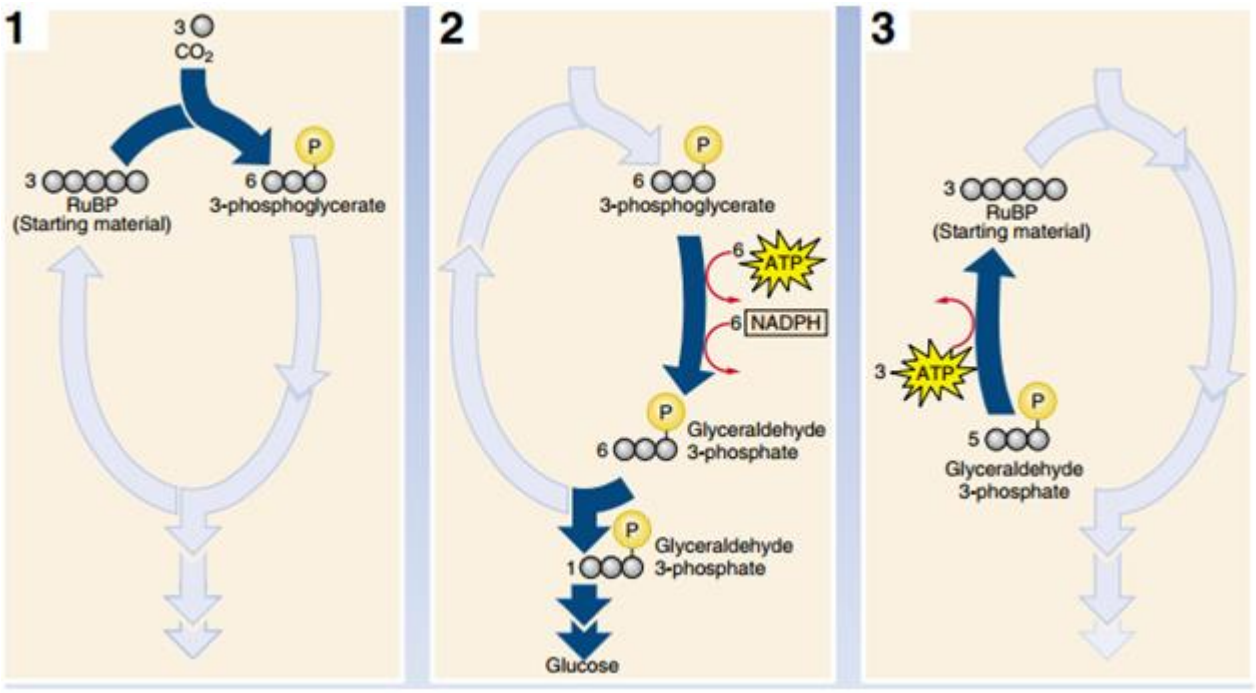
Dark Reaction of Photosynthesis (or) Light-independent Reaction

- Dark reaction is also called carbon-fixing reaction.
- It is a light-independent process in which sugar molecules are formed from the water and carbon dioxide molecules.
- The dark reaction occurs in the stroma of the chloroplast where they utilize the NADPH and ATP products of the light reaction.
- Plants capture the carbon dioxide from the atmosphere through stomata and proceed to the Calvin photosynthesis cycle.
- In the **Calvin cycle**, the ATP and NADPH formed during light reaction drive the reaction and convert 6 molecules of carbon dioxide into one sugar molecule or glucose.

The chemical equation for the dark reaction can be reduced to:

$3CO_2 + 6\ NADPH + 5H_2O + 9ATP \rightarrow G3P + 2H+ + 6\ NADP+ + 9\ ADP + 8\ Pi$

* G3P – glyceraldehyde-3-phosphate



Calvin photosynthesis Cycle (Dark Reaction)

Importance of Photosynthesis

- Photosynthesis is essential for the existence of all life on earth. It serves a crucial role in the food chain – the plants create their food using this process, thereby, forming the primary producers.
- Photosynthesis is also responsible for the production of oxygen – which is needed by most organisms for their survival.

Frequently Asked Questions

1. What is Photosynthesis? Explain the process of photosynthesis.

Photosynthesis is a biological process utilized by all green plants to synthesize their own nutrients. The process of photosynthesis requires solar energy, water and carbon dioxide. The by-product of this process is oxygen.

2. What is the significance of Photosynthesis?

During photosynthesis, oxygen gas is liberated out into the environment and is utilized by humans, animals and other living species during the process of respiration.

3. List out the factors influencing Photosynthesis?

There are several factors that affect the rate of photosynthesis. Light intensity, water, soil pH, carbon dioxide concentration, temperature and other climatic conditions are the main factors affecting the rate of photosynthesis.

4. What are the different stages of Photosynthesis?

Photosynthesis takes place in two stages, namely light-dependent reactions and light-independent reactions. Light-dependent reactions are also called light reactions and occur during the day time. Light-independent reaction is also called the dark reaction or the Calvin cycle.

5. What is the Calvin Cycle?

The Calvin cycle is also called the light-independent reaction. The complete process of the Calvin cycle takes place in the stroma of the chloroplasts.

6. Write down the Photosynthesis Equation.

$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$

NUCLEUS STRUCTURE AND FUNCTIONS

- The cell nucleus is a membrane-bound structure that contains the cell's hereditary information and controls the cell's growth and reproduction.
- It is the command center of a eukaryotic cell and is commonly the most prominent organelle in a cell accounting for about 10 percent of the cell's volume.
- In general, a eukaryotic cell has only one nucleus. However, some eukaryotic cells are enucleated cells (without a nucleus), for example, red blood cells (RBCs); whereas, some are multinucleate (consists of two or more nuclei), for example, slime **molds.**

- The nucleus is separated from the rest of the cell or the **cytoplasm** by a nuclear membrane.
- As the nucleus regulates the integrity of genes and gene expression, it is also referred to as the control center of a cell.

Nucleus

Structure and Functions

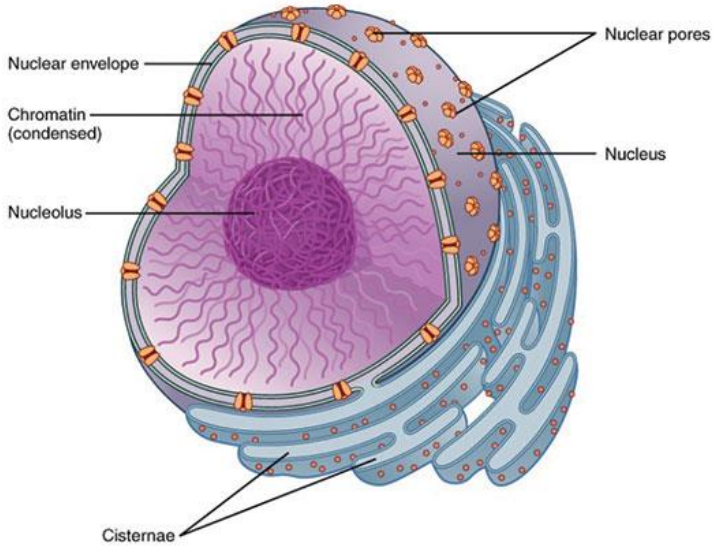


Figure: Diagram of Nucleus

Structure of Nucleus

The structure of a nucleus encompasses the nuclear membrane, nucleoplasm, chromosomes, and nucleolus.

Nuclear Membrane

- The nuclear membrane is a double-layered structure that encloses the contents of the nucleus. The outer layer of the membrane is connected to the endoplasmic reticulum.
- Like the cell membrane, the nuclear envelope consists of phospholipids that form a lipid bilayer.
- The envelope helps to maintain the shape of the nucleus and assists in regulating the flow of molecules into and out of the nucleus through nuclear pores. The nucleus communicates with the remaining of the cell or the cytoplasm through several openings called nuclear pores.
- Such nuclear pores are the sites for the exchange of large molecules (proteins and RNA) between the nucleus and cytoplasm.
- A fluid-filled space or perinuclear space is present between the two layers of a nuclear membrane.

Nucleoplasm

- Nucleoplasm is the gelatinous substance within the nuclear envelope.
- Also called karyoplasm, this semi-aqueous material is similar to the cytoplasm and is composed mainly of water with dissolved salts, enzymes, and organic molecules suspended within.
- The nucleolus and chromosomes are surrounded by nucleoplasm, which functions to cushion and protect the contents of the nucleus.

- Nucleoplasm also supports the nucleus by helping to maintain its shape. Additionally, nucleoplasm provides a medium by which materials, such as enzymes and nucleotides (DNA and RNA subunits), can be transported throughout the nucleus. Substances are exchanged between the cytoplasm and nucleoplasm through nuclear pores.

Nucleolus

- Contained within the nucleus is a dense, membrane-less structure composed of RNA and proteins called the nucleolus.
- Some of the eukaryotic organisms have a nucleus that contains up to four nucleoli.
- The nucleolus contains nucleolar organizers, which are parts of chromosomes with the genes for ribosome synthesis on them. The nucleolus helps to synthesize ribosomes by transcribing and assembling ribosomal RNA subunits. These subunits join together to form a ribosome during protein synthesis.
- The nucleolus disappears when a cell undergoes division and is reformed after the completion of cell division.

Chromosomes

- The nucleus is the organelle that houses chromosomes.
- Chromosomes consist of DNA, which contains heredity information and instructions for cell growth, development, and reproduction.
- Chromosomes are present in the form of strings of DNA and histones (protein molecules) called chromatin.
- When a cell is “resting” i.e. not dividing, the chromosomes are organized into long entangled structures called chromatin.
- The chromatin is further classified into heterochromatin and euchromatin based on the functions. The former type is a highly condensed, transcriptionally inactive form, mostly present adjacent to the nuclear membrane. On the other hand, euchromatin is a delicate, less condensed organization of chromatin, which is found abundantly in a transcribing cell.

Besides the nucleolus, the nucleus contains a number of other non-membrane-delineated bodies. These include Cajal bodies, Gemini of coiled bodies, polymorphic interphase karyosome association (PIKA), promyelocytic leukemia (PML) bodies, paraspeckles, and splicing speckles.

Functions of Nucleus

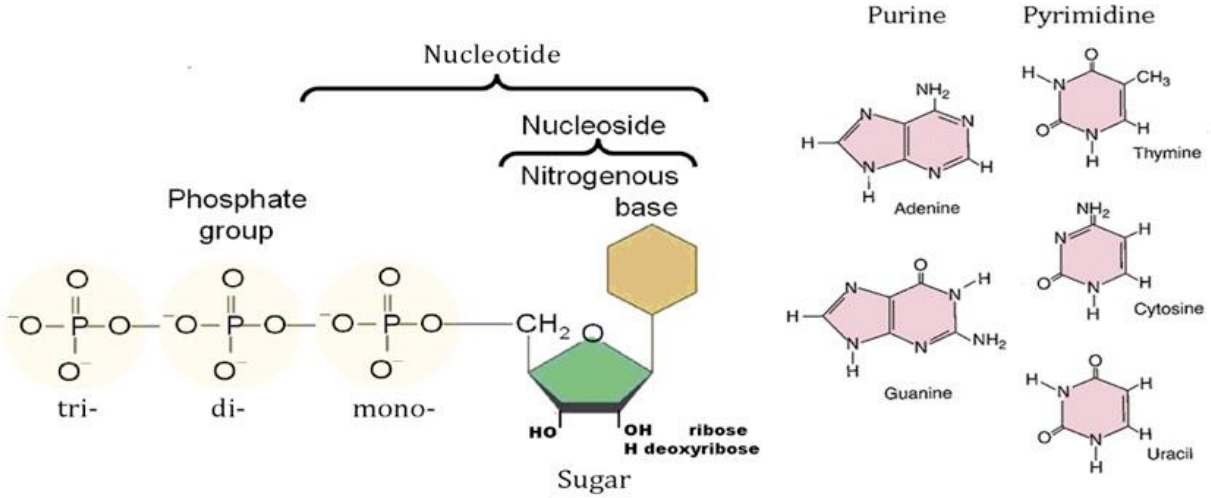
The nucleus provides a site for genetic transcription that is segregated from the location of translation in the cytoplasm, allowing levels of gene regulation that are not available to prokaryotes. The main function of the cell nucleus is to control gene expression and mediate the replication of DNA during the cell cycle.

- It controls the hereditary characteristics of an organism.
- The organelle is also responsible for 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 chromatin.

- Storage of proteins and RNA (ribonucleic acid) in the nucleolus.
- The nucleus is a site for transcription in which messenger RNA (mRNA) are produced for protein synthesis.
- During the cell division, chromatins are 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.

Nucleic Acids- Nucleosides and Nucleotides

- Nucleotide is any member of the class of organic compounds in which the molecular structure comprises a nitrogen-containing unit (base) linked to a sugar and a phosphate group.
- They are monomeric units of nucleic acids and also serve as sources of chemical energy (ATP, GTP), participate in cellular signalling (cAMP, cGMP) and function as important cofactors of enzymatic reactions (coA, FAD, FMN, NAD+).
- The molecule without the phosphate group of nucleotides is called as nucleoside.
- Nucleosides are glycosylamines consisting simply of a nitrogenous base and a five-carbon sugar (either ribose or deoxyribose).



Structure of Nucleotides

A single nucleotide is made up of three components: a nitrogen-containing base, a five-carbon sugar (pentose), and at least one phosphate group With all three joined, a nucleotide is also termed a “nucleoside phosphate”.
Individual phosphate molecules repetitively connect the sugar-ring molecules in two adjacent nucleotide monomers, thereby connecting the nucleotide monomers of a nucleic acid end-to-end into a long chain.

Unlike in nucleic acid nucleotides, singular cyclic nucleotides are formed when the phosphate group is bound twice to the same sugar molecule, i.e., at the corners of the sugar hydroxyl groups

Nitrogenous bases

- The nitrogenous base is either a purine or a pyrimidine.
- There are five major bases found in cells. The derivatives of purine are called adenine and guanine, and the derivatives of pyrimidine are called thymine, cytosine and uracil.
- Purines include adenine and guanine and have two rings.
- Adenine has an ammonia group on its rings, whereas guanine has a ketone group.
- Pyrimidines include cytosine, thiamine, and uracil and have one ring.
- Thymine (found in **DNA**) and uracil (found in RNA) are similar in that they both have ketone groups, but thymine has an extra methyl group on its ring.
- Bonds between guanine and cytosine (three hydrogen bonds) are stronger than bonds between adenine and thymine (two hydrogen bonds).

Pentose Sugar

- The five-carbon sugar is either a ribose (in RNA) or a deoxyribose (in DNA) molecule.
- In nucleotides, both types of pentose sugars are in their beta-furanose (closed five-membered ring) form.

Structure of Nucleosides

- While a nucleotide is composed of a nucleobase, a five-carbon sugar, and one or more phosphate groups, a nucleoside has only a nitrogenous base and a five-carbon sugar.
- In a nucleoside, the base is bound to either ribose or deoxyribose via a beta-glycosidic linkage at 1’ position.
- Examples of nucleosides include cytidine, uridine, adenosine, guanosine, thymidine and inosine.

Properties of Nucleotides

Properties of purine bases

- Sparingly soluble in water
- Absorb light in UV region at 260 nm. (detection & quantitation of nucleotides)
- Capable of forming hydrogen bond
- Aromatic base atoms numbered 1 to 9
- Purine ring is formed by fusion of pyrimidine ring with imidazole ring.
- Numbering is anticlockwise.

Adenine : Chemically it is 6-aminopurine

Guanine : Chemically it is 2-amino,6-oxy purine

Can be present as lactam & lactim form

Properties of pyrimidine bases

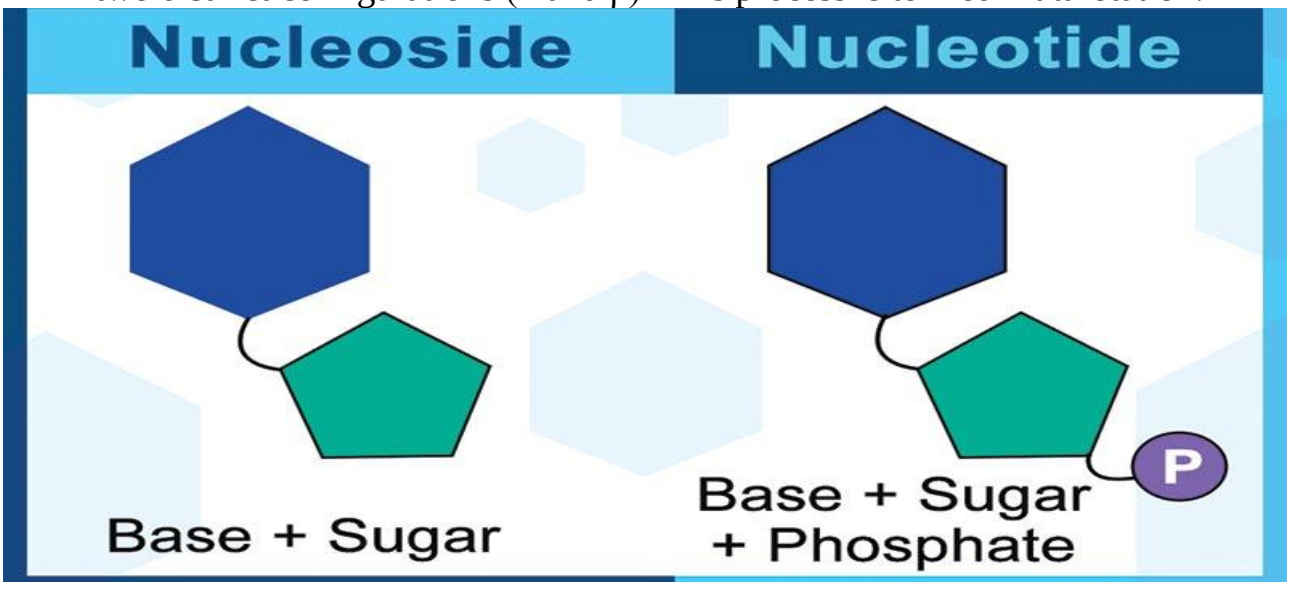
- Soluble at body pH

- Also absorb UV light at 260 nm
- Capable of forming hydrogen bond
- Aromatic base atoms are numbered 1 to 6 for pyrimidine.
- Atoms or group attached to base atoms have same number as the ring atom to which they are bonded.

Cytosine: Chemically is 2-oxy ,4-amino pyrimidine
Exist both lactam or lactim form
Thymine: Chemically is 2,4 dioxy ,5-methyl pyrimidine
Occurs only in DNA
Uracil: Chemically is 2,4 dioxy pyrimidine
Found only in RNA

Properties of Pentose Sugars

- A pentose is a monosaccharide with five carbon atoms.
- Ribose is the most common pentose with one oxygen atom attached to each carbon atom.
- Deoxyribose sugar is derived from the sugar ribose by loss of an oxygen atom.
- The aldehyde functional group in the carbohydrates react with neighbouring hydroxyl functional groups to form intramolecular hemiacetals.
- The resulting ring structure is related to furan, and is termed a furanose.
- The ring spontaneously opens and closes, allowing rotation to occur about the bond between the carbonyl group and the neighboring carbon atom yielding two distinct configurations (α and β). This process is termed mutarotation.



Classification of Nucleotides

On the basis of the type of sugar present, nucleotides may be:

1. **Ribonucleotides** if the sugar is ribose.
2. **Deoxyribonucleotides** if the sugar is deoxyribose.

Classification of Nucleosides

On the basis of type of nitrogenous bases present, nucleoside derivatives may be also grouped as following:

1. **Adenosine nucleotides:** ATP, ADP, AMP, Cyclic AMP
2. **Guanosine nucleotides:** GTP, GDP, GMP, Cyclic GMP
3. **Cytidine nucleotides:** CTP, CDP, CMP and certain deoxy CDP derivatives of glucose, choline and ethanolamine
4. **Uridine nucleotides:** UDP
5. **Miscellaneous** : PAPS (active sulphate), SAM (active methionine), certain coenzymes like NAD+, FAD, FMN, Cobamide coenzyme, CoA

Functions of Nucleotides

- The nucleotides are of great importance to living organisms, as they are the building blocks of nucleic acids, the substances that control all hereditary characteristics.
- Polynucleotides consist of nucleosides joined by 3′,5′-phosphodiester bridges. The genetic message resides in the sequence of bases along the polynucleotide chain.
- Nucleotides have a variety of roles in cellular metabolism. They are the energy currency in metabolic transactions.
- They act as essential chemical links in the response of cells to hormones and other extracellular stimuli.
- They are the structural components of an array of enzyme cofactors and metabolic intermediates.
- The structure of every protein, and ultimately of every biomolecule and cellular component, is a product of information programmed into the nucleotide sequence of a cell’s nucleic acids.
- Serving as energy stores for future use in phosphate transfer reactions. These reactions are predominantly carried out by ATP.
- Forming a portion of several important coenzymes such as NAD+, NADP+, FAD and coenzyme A.
- Serving as mediators of numerous important cellular processes such as second messengers in signal transduction events. The predominant second messenger is cyclic-AMP (cAMP), a cyclic derivative of AMP formed from ATP.
- Serving as neurotransmitters and as signal receptor ligands. Adenosine can function as an inhibitory neurotransmitter, while ATP also affects synaptic neurotransmission throughout the central and peripheral nervous systems. ADP is an important activator of platelet functions resulting in control of blood coagulation.
- Controlling numerous enzymatic reactions through allosteric effects on enzyme activity.
- Serving as activated intermediates in numerous biosynthetic reactions. These activated intermediates include S-adenosylmethionine (S-AdoMet or

SAM) involved in methyl transfer reactions as well as the many sugar coupled nucleotides involved in glycogen and glycoprotein synthesis.

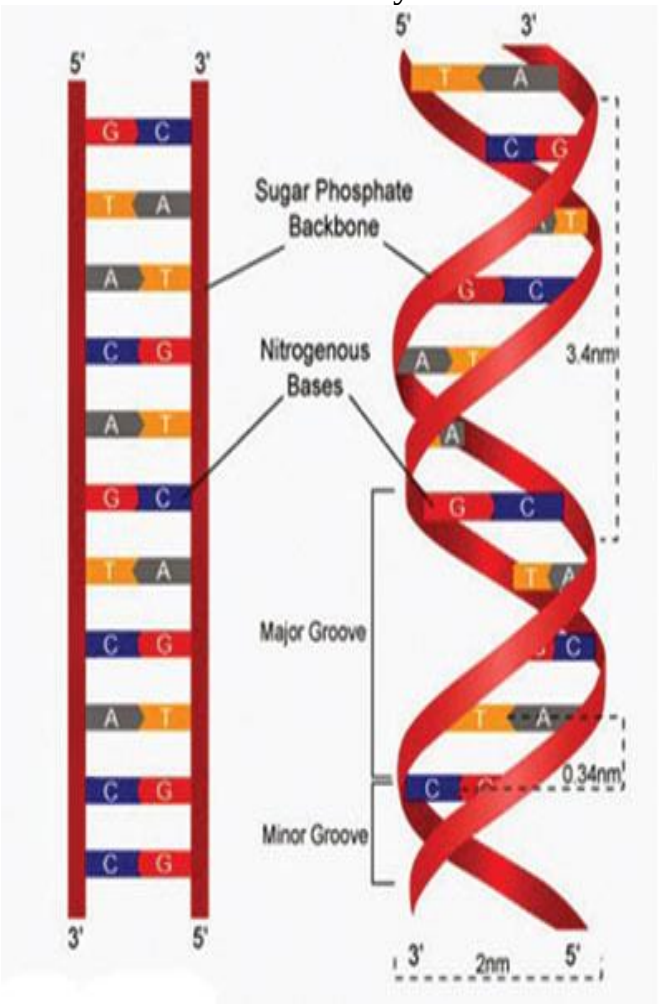
WATSON AND CRICK DNA MODEL

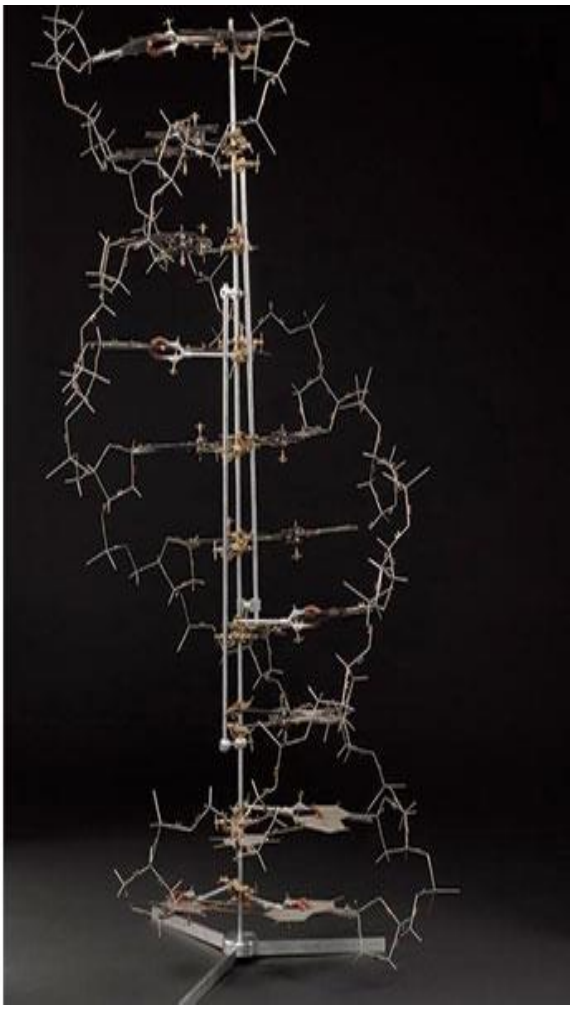
- **DNA** stands for Deoxyribonucleic acid which is a molecule that contains the instructions an organism needs to develop, live and reproduce.
- It is a type of nucleic acid and is one of the four major types of macromolecules that are known to be essential for all forms of life.

DNA Model

- The three-dimensional structure of DNA, first proposed by James D. Watson and Francis H. C. Crick in 1953, consists of two long helical strands that are coiled around a common axis to form a double helix.
- Each DNA molecule is comprised of two biopolymer strands coiling around each other.
- Each strand has a 5′end (with a phosphate group) and a 3′end (with a hydroxyl group).
- The strands are antiparallel, meaning that one strand runs in a 5′to 3′direction, while the other strand runs in a 3′to 5′direction.
- The diameter of the double helix is 2nm and the double helical structure repeats at an interval of 3.4nm which corresponds to ten base pairs.
- The two strands are held together by hydrogen bonds and are complementary to each other.
- The two DNA strands are called polynucleotides, as they are made of simpler monomer units called nucleotides. Basically, the DNA is composed of deoxyribonucleotides.
- The deoxyribonucleotides are linked together by 3′- 5′phosphodiester bonds.
- The nitrogenous bases that compose the deoxyribonucleotides include adenine, cytosine, thymine, and guanine.
- The structure of DNA -DNA is a double helix structure because it looks like a twisted ladder.
- The sides of the ladder are made of alternating sugar (deoxyribose) and phosphate molecules while the steps of the ladder are made up of a pair of nitrogen bases.
- As a result of the double helical nature of DNA, the molecule has two asymmetric grooves. One groove is smaller than the other.
- This asymmetry is a result of the geometrical configuration of the bonds between the phosphate, sugar, and base groups that forces the base groups to attach at 120-degree angles instead of 180 degrees.

- The larger groove is called the major groove, occurs when the backbones are far apart; while the smaller one is called the minor groove, and occurs when they are close together.
- Since the major and minor grooves expose the edges of the bases, the grooves can be used to tell the base sequence of a specific DNA molecule.
- The possibility for such recognition is critical since proteins must be able to recognize specific DNA sequences on which to bind in order for the proper functions of the body and cell to be carried out.





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SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOTECHNOLOGY

UNIT – IV – CELL BIOLOGY – SBB1101

SBB1101	CELL BIOLOGY	L	T	P	Credits	Total Marks
		3	1	0	4	100

COURSE OBJECTIVES

- Cell biology is the study of the structure and function of prokaryotic and eukaryotic cells. In this course the students will learn different areas of cellular biology including the structure and functions of cell, its organelles, synthesis and function of macromolecules such as carbohydrate, protein, lipid, DNA & RNA; membrane structure and function; bioenergetics; cellular communication; and microscopic techniques to understand the cell structure.

UNIT 1 FUNDAMENTALS OF CELL STRUCTURE **12 Hrs.**

Discovery of cells; Basic properties of cells; Different classes of cells – Prokaryotic and eukaryotic cells. Cell division: Cell cycle; mitosis; meiosis, binary fission.

UNIT 2 CELLULAR MEMBRANES AND MATRICES **12 Hrs.**

Chemical composition and fluidity of membranes; dynamic nature of membranes; transportation across cell membrane; membrane potentials; extracellular matrices – structure and function; cytoskeleton – structure and function.

UNIT 3 CELLULAR ORGANELLES IN ENERGY METABOLISM **12 Hrs.**

Mitochondria – structure and function; Chloroplast – structure and function. Structure of nucleus – nuclear membrane, nucleolus, chromatin, structure of nucleic acids

UNIT 4 CELLULAR ORGANELLES IN METABOLISM **12 Hrs.**

Endoplasmic reticulum – smooth & rough; function of endoplasmic reticulum; Golgi complex – structure and function; Ribosomes – Types, structure and function; Morphology and functions of peroxisomes and glyoxisomes; Plant cell vacuoles.

UNIT 5 TRANSPORT ACROSS CELL MEMBRANE **12 Hrs.**

Passive and active transports, Permeases, Sodium -potassium pumps, Ca 2+ ATPase pump, ATP dependant proton pumps, co-transport, symport, antiport, Endocytosis and Exocytosis. Introduction to intra and extra cellular products of medicinal use.

Max Hours.60

Text Books

1. Freifelder D. 1985. Molecular Biology, Narosa Publishing House. New Delhi.
2. Lewin B. 2007. Genes IX. Oxford University Press, London.
3. Ajoy Paul. 2011. Textbook of Cell and Molecular Biology. Books and Allied Ltd.
4. Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. 2008. Molecular Biology of Cell. 6th Edition. Garland Science, Taylor & Francis group Publishers.
5. Harvey Lodish, Arnold Berk, S Lawrence Zipursky, Paul Matsudaira, David Baltimore, and James Darnell. 1995. Molecular Cell Biology. 3rd Edition. W.H. Freeman Publishers.

END SEMESTER EXAMINATION QUESTION PAPER PATTERN

Max. Marks : 100 **Exam Duration : 3 Hrs.**

PART A : 10 questions of 2 marks each - No choice **20 Marks**

PART B : 2 questions from each UNIT of internal choice; each carrying 16 marks **80 Marks**

UNIT: 4

CELLULAR ORGANELLES IN METABOLISM

Endoplasmic reticulum-smooth & rough, function of endoplasmic reticulum; Golgi complex-structure and function: Ribosomes-Types, structure and function, Morphology and functions of peroxisomes and glyoxisomes, Plant cell Vacuoles.

ENDOPLASMIC RETICULUM (ER)- DEFINITION, STRUCTURE, FUNCTIONS AND DIAGRAM

Within the cytoplasm of most animal cells is an extensive network (reticulum) of membrane-limited channels, collectively called the endoplasmic reticulum (or ER).

The endoplasmic reticulum is a name derived from the fact that in the light microscope it looks like a "net in the cytoplasm."

The endoplasmic reticulum is only present in the eukaryotic cells. However, the occurrence of the endoplasmic reticulum varies from cell to cell.

For example, the erythrocytes (RBC), egg and embryonic cells lack in the endoplasmic reticulum.

Some portion of ER membranes remains continuous with the plasma membrane and the nuclear envelope.

ER may be rough or smooth. The outer surface of rough ER has attached ribosomes, whereas smooth ER does not have attached ribosomes.

The endoplasmic reticulum acts as secretory, storage, circulatory and nervous system for the cell. It is also the site of the biogenesis of cellular membranes.

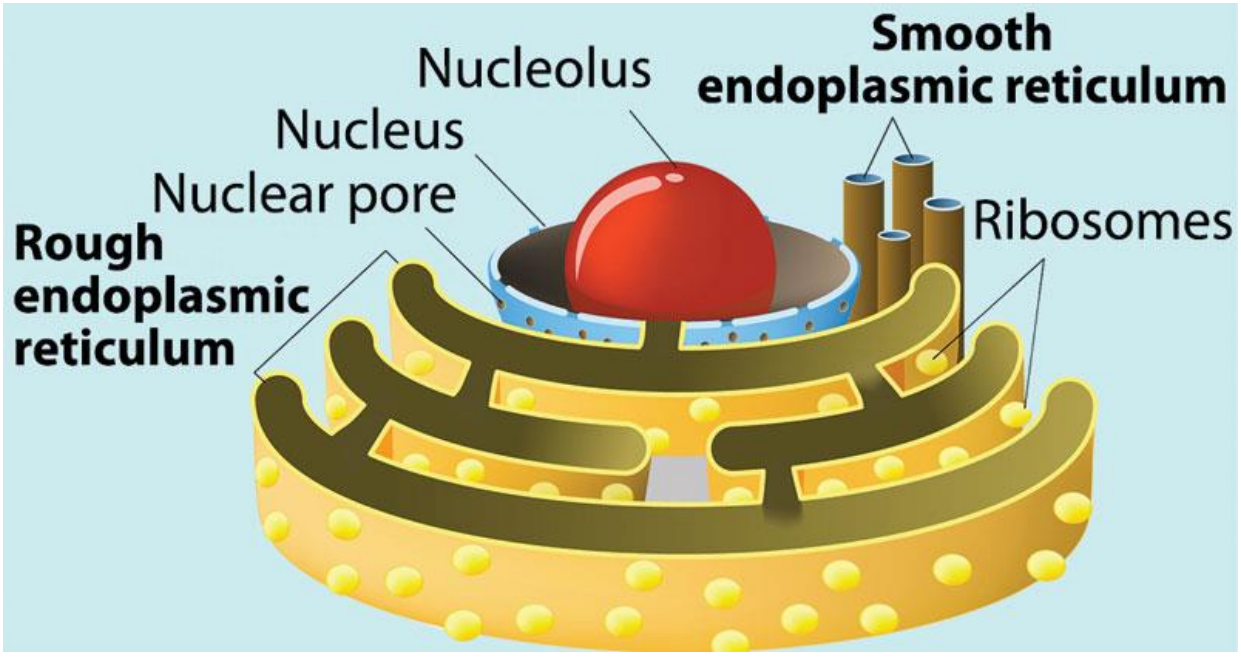

Figure: Diagram of Endoplasmic Reticulum (ER)

The membrane of the endoplasmic reticulum is 50 to 60 Aº thickness and fluid-mosaic like the unit membrane of the plasma membrane.

The membranes of the endoplasmic reticulum are found to contain many kinds of enzymes that are needed for various important synthetic activities. The most important enzymes are the stearases, NADH-cytochrome C reductase, NADH diaphorase, glucose-6-phosphatase, and Mg++ activated ATPase.

The membrane of endoplasmic reticulum remains continuous with the membranes of the plasma membrane, nuclear membrane, and Golgi apparatus.

The cavity of the endoplasmic reticulum is well developed and acts as a passage for the secretory products.

The endoplasmic reticulum may occur in the following three forms:

Lamellar form or cisternae

Vesicular form or vesicle and

Tubular form or tubules.

The Cisternae

RER usually exists as cisternae that occur in those cells which have synthetic roles as the cells of the pancreas, notochord, and brain.

The cisternae are long, flattened, sac-like, unbranched tubules having a diameter of 40 to 50 μm.

They remain arranged parallelly in bundles or stakes.

The Vesicles

The vesicles are oval; membrane-bound vacuolar structures having a diameter of 25 to 500 μm.

They often remain isolated in the cytoplasm and occur in most cells but especially abundant in the SER.

The Tubules

The tubules are branched structures forming the reticular system along with the cisternae and vesicles.

They usually have a diameter from 50 to 190 μm and occur almost in all the cells.

Tubular form of ER is often found in SER and is dynamic in nature, i.e., it is associated with membrane movements, fission and fusion between membranes of cytocavity network.

Types of Endoplasmic Reticulum (ER)

1. Smooth Endoplasmic Reticulum

They are also called as the agranular endoplasmic reticulum.

This type of endoplasmic reticulum possesses smooth walls because the ribosomes are not attached to its membranes.

The smooth type of endoplasmic reticulum occurs mostly in those cells, which are involved in the metabolism of lipids (including steroids) and glycogen. Eg. adipose cells, interstitial cells, glycogen storing cells of the liver, conduction fibers of heart, spermatocytes, and leucocytes.

2. Rough Endoplasmic Reticulum

It possesses rough walls because the ribosomes remain attached to its membranes.

On their membranes, rough ER (RER) contains certain ribosome specific, transmembrane glycoproteins, called ribophorins I and II, to which are attached the ribosomes while engaged in polypeptide synthesis.

The rough type of endoplasmic reticulum is found abundantly in those cells which are active in protein syntheses such as pancreatic cells, plasma cells, goblet cells, and liver cells.

Functions

- Functions of smooth ER include lipid metabolism (both catabolism and anabolism; they synthesize a variety of phospholipids, cholesterol, and steroids).
- Glycogenolysis (degradation of glycogen; glycogen being polymerized in the cytosol).
- Drug detoxification (by the help of the cytochrome P-450).
- The endoplasmic reticulum provides an ultrastructural skeletal framework to the cell and gives mechanical support to the colloidal cytoplasmic matrix.
- The exchange of molecules by the process of osmosis, diffusion and active transport occurs through the membranes of the endoplasmic reticulum.
- The endoplasmic reticulum is the main component of the endomembrane system, also called the cytoplasmic vacuolar system or cytocavity network.

- The endoplasmic membranes contain many enzymes that perform various synthetic and metabolic activities. Further, the endoplasmic reticulum provides an increased surface for various enzymatic reactions.
- The endoplasmic reticulum acts as an intracellular circulatory or transporting system.
- As a growing secretory polypeptide emerges from the ribosome, it passes through the RER membrane and gets accumulated in the lumen of RER. Here, the polypeptide chains undergo tailoring, maturation, and molecular folding to form functional secondary or tertiary protein molecules.
- RER pinches off certain tiny protein-filled vesicles which ultimately get fused to cis Golgi.
- The ER membranes are found to conduct intra-cellular impulses. For example, the sarcoplasmic reticulum transmits impulses from the surface membrane into the deep region of the muscle fibers.
- The ER membranes form the new nuclear envelope after each nuclear division.
- The SER contains several key enzymes that catalyze the synthesis of cholesterol which is also a precursor substance for the biosynthesis of two types of compounds— the steroid hormones and bile acids.
- RER also synthesize membrane proteins and glycoproteins which are cotranslationally inserted into the rough ER membranes. Thus, the endoplasmic reticulum is the site of the biogenesis of cellular membranes.

GOLGI COMPLEX STRUCTURE AND FUNCTION

- The Golgi apparatus or the Golgi body or Golgi complex or simply Golgi is a cellular organelle present in most of the cells of the eukaryotic organisms.
- It is referred to as the manufacturing and the shipping center of the cell.
- Golgi is involved in the packaging of the protein molecules before they are sent to their destination. These organelles help in processing and packaging the macromolecules like **proteins** and lipids that are synthesized by the cell and hence act as the ‘post office’ of the cell.
- Golgi apparatus was discovered in
- the year 1898 by an Italian biologist Camillo Golgi.

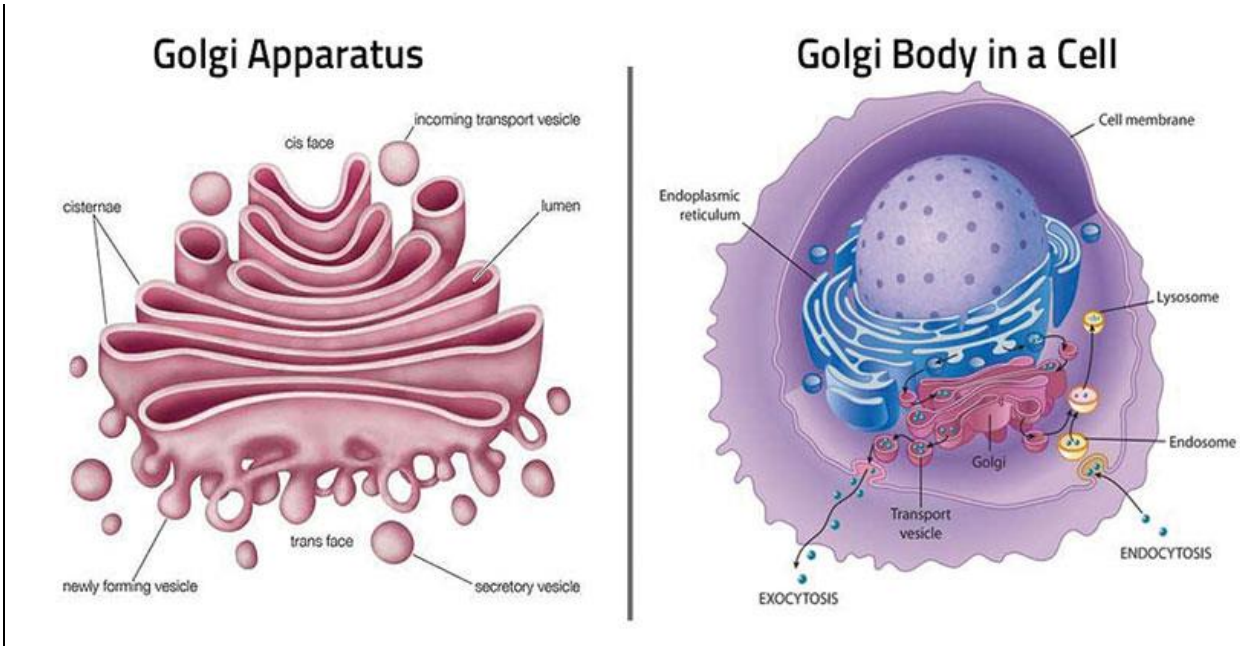

Figure: Diagram of the Golgi Apparatus

Structure of Golgi Apparatus

- Under the electron microscope, the Golgi apparatus is seen to be composed of stacks of flattened structures that contain numerous vesicles containing secretory granules.
- The Golgi apparatus is morphologically very similar in both plant and animal cells. However, it is extremely pleomorphic: in some cell types it appears compact and limited, in others spread out and reticular (net-like).
- Typically, however, Golgi apparatus appears as a complex array of **interconnecting tubules, vesicles, and cisternae.**

A. Cisternae

- It is the simplest unit of the Golgi apparatus is the cisterna.
- Cisternae (about 1 μm in diameter) are central, flattened, plate-like or saucer-like closed compartments that are held in parallel bundles or stacks one above the other.
- In each stack, cisternae are separated by a space of 20 to 30 nm which may contain rod-like elements or fibers.
- Each stack of cisternae forms a dictyosome which may contain 5 to 6 Golgi cisternae in animal cells or 20 or more cisternae in plant cells.
- Each cisterna is bounded by a smooth unit membrane (7.5 nm thick), having a lumen varying in width from about 500 to 1000 nm.
- The margins of each cisterna are gently curved so that the entire dictyosome of the Golgi apparatus takes on a bow-like appearance.
- The cisternae at the convex end of the dictyosome comprise proximal, forming or cis-face and cisternae at the concave end of the dictyosome comprise the distal, maturing or trans-face.

B. Tubules

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

C. Vesicles

The vesicles (60 nm in diameter) are of three types:

(i) Transitional vesicles are small membrane limited vesicles which are thought to form as blebs from the transitional ER to migrate and converge to cis face of Golgi, where they coalesce to form new cisternae.

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

(iii) Clathrin-coated vesicles are spherical protuberances, about 50 μm in diameter and with a rough surface. They are found at the periphery of the organelle, usually at the ends of single tubules, and are morphologically quite distinct from the secretory vesicles. The clathrin-coated vesicles are known to play a role in intracellular traffic of membranes and of secretory products, i.e., between ER and Golgi, as well as, between the GELR region and the endosomal and lysosomal compartments.

Functions of Golgi Apparatus

1. Golgi vesicles are often, referred to **as the "traffic police" of the cell**. They play a key role in sorting many of the cell's proteins and membrane constituents, and in directing them to their proper destinations.
   - To perform this function, the Golgi vesicles contain different sets of enzymes in different types of vesicles— cis, middle and trans cisternae—that react with and modify secretory proteins passing through the Golgi lumen or membrane proteins and glycoproteins that are transiently in the Golgi membranes as they are en route to their final destinations.
   - The Golgi apparatus hence acts as the assembly factory of the cell where the raw materials are directed to the Golgi apparatus before being passed out from the cell.

2. In animals, the Golgi apparatus is involved in the packaging and exocytosis of the following materials :
   - Zymogen of exocrine pancreatic cells;
   - Mucus (=a glycoprotein) secretion by goblet cells of the intestine ;
   - Lactoprotein (casein) secretion by mammary gland cells (Merocrine secretion) ;
   - Secretion of compounds (thyroglobulins) of thyroxine hormone by thyroid cells;
   - Secretion of tropocollagen and collagen ;
   - Formation of melanin granules and other pigments; and
   - Formation of yolk and vitelline membrane of growing primary oocytes.

3. It is also involved in the formation of certain cellular organelles such as plasma membrane, lysosomes, acrosome of spermatozoa and cortical granules of a variety of oocytes.

4. They are also involved in the transport of lipid molecules around the cell.
5. The Golgi complex also plays an important role in the production of proteoglycans. The proteoglycans are molecules that are present in the extracellular matrix of the animal cells.
6. It is also a major site of synthesis of carbohydrates. These carbohydratres include the synthesis of glycosaminoglycans, Golgi attaches to these polysaccharides which then attaches to a protein produced in the endoplasmic reticulum to form proteoglycans.
7. The Golgi involves in the sulfation process of certain molecules.
8. The process of phosphorylation of molecules by the Golgi requires the import of ATP into the lumen of the Golgi.
9. In plants, Golgi apparatus is mainly involved in the secretion of materials of primary and secondary cell walls (e.g., formation and export of glycoproteins, lipids, pectins and monomers for hemicellulose, cellulose, lignin, etc.)

RIBOSOMES-TYPES, STRUCTURE AND FUNCTION

- The ribosome word is derived – 'ribo' from ribonucleic acid and 'somes' from the Greek word 'soma' which means 'body'.
- Ribosomes are tiny spheroidal dense particles (of 150 to 200 A^0 diameters) that are primarily found in most prokaryotic and eukaryotic.
- They are sites of **protein synthesis**.
- They are structures containing approximately equal amounts of RNA and proteins and serve as a scaffold for the ordered interaction of the numerous molecules involved in protein synthesis.
- The ribosomes occur in cells, both prokaryotic and eukaryotic cells.
- In prokaryotic cells, the ribosomes often occur freely in the cytoplasm.
- In eukaryotic cells, the ribosomes either occur freely in the cytoplasm or remain attached to the outer surface of the membrane of the endoplasmic reticulum.
- The location of the ribosomes in a cell determines what kind of protein it makes.
- If the ribosomes are floating freely throughout the cell, it will make proteins that will be utilized within the cell itself.
- When ribosomes are attached to the endoplasmic reticulum, it is referred to as rough endoplasmic reticulum or rough ER.
- Proteins made on the rough ER are used for usage inside the cell or outside the cell.
- The number of ribosomes in a cell depends on the activity of the cell.
- On average in a mammalian cell, there can be about 10 million ribosomes.

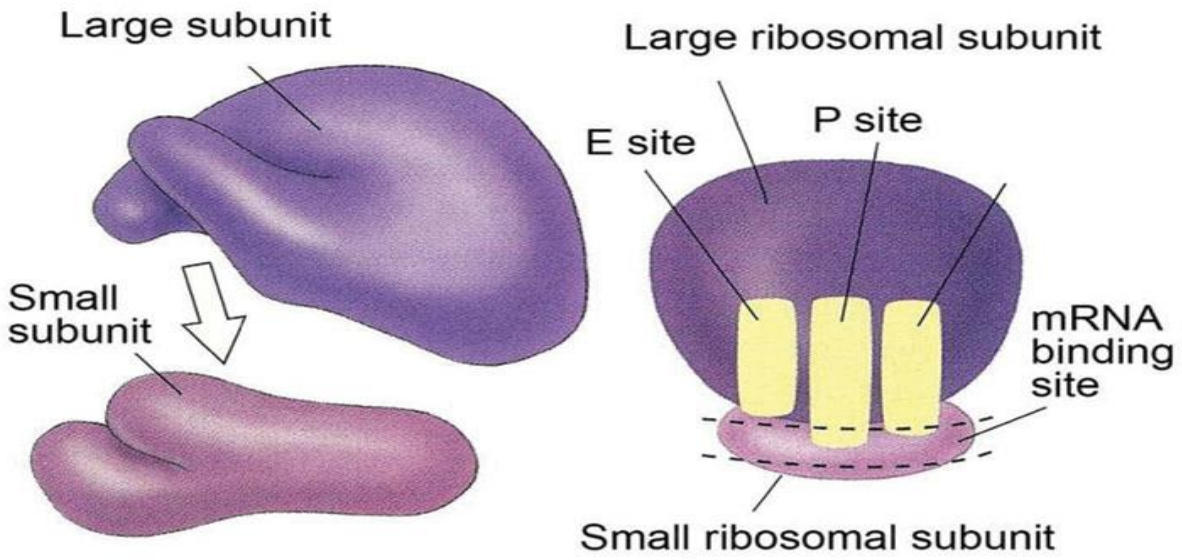

Figure: Diagram of Ribosomes

Structure of Ribosomes

- A ribosome is made from complexes of RNAs and proteins and is, therefore, a ribonucleoprotein.
- Around 37 to 62% of RNA is comprised of RNA and the rest is proteins.
- Each ribosome is divided into two subunits:

1. **A smaller subunit** which binds to a larger subunit and the mRNA pattern, and
2. **A larger subunit** which binds to the tRNA, the amino acids, and the smaller subunit.

- Prokaryotes have 70S ribosomes respectively subunits comprising the little subunit of 30S and the bigger subunit of 50S.
- Their small subunit has a 16S RNA subunit (consisting of 1540 nucleotides) bound to 21 proteins.
- The large subunit is composed of a 5S RNA subunit (120 nucleotides), a 23S RNA subunit (2900 nucleotides) and 31 proteins.
- Eukaryotes have 80S ribosomes respectively comprising of little (40S) and substantial (60S) subunits.
- The smaller 40S ribosomal subunit is prolate ellipsoid in shape and consists of one molecule of 18S ribosomal RNA (or rRNA) and 30 proteins (named as S1, S2, S3, and so on).
- The larger 60S ribosomal subunit is round in shape and contains a channel through which growing polypeptide chain makes its exit.
- It consists of three types of rRNA molecules, i.e., 28S rRNA, 5.8 rRNA and 5S rRNA, and 40 proteins (named as L1, L2, L3 and so on).
- The differences between the ribosomes of bacterial and eukaryotic are used to create antibiotics that can destroy bacterial infection without harming human cells.
- The ribosomes seen in the chloroplasts of mitochondria of eukaryotes are comprised of big and little subunits composed of proteins inside a 70S particle.

- The ribosomes share a core structure that is similar to all ribosomes despite differences in its size.
- The two subunits fit together and work as one to translate the mRNA into a polypeptide chain during protein synthesis.
- Because they are formed from two subunits of non-equal size, they are slightly longer in the axis than in diameter.
- During protein synthesis, when multiple ribosomes are attached to the same mRNA strand, this structure is known as polysome.
- The existence of ribosomes is temporary, after the synthesis of polypeptide the two sub-units separate and are reused or broken up.

Functions of Ribosomes

- The ribosome is a complex molecular machine, found within all living cells, that serves as the site of biological protein synthesis (translation).
- Ribosomes link amino acids together in the order specified by messenger RNA (mRNA) molecules.

MORPHOLOGY AND FUNCTIONS OF PEROXISOMES

Peroxisomes are small vesicles, single membrane-bound organelles found around the eukaryotic cells. They contain digestive enzymes for breaking down toxic materials in the cell and oxidative enzymes for metabolic activity. They are a heterogeneous group of organelles and the presence of the marker enzymes distinguished them from other **cell organelles.**

Peroxisomes play an important role in lipid production and are also involved in the conversion of reactive oxygen species such as hydrogen peroxide into safer molecules like water and oxygen.

The peroxisome derives its name from the fact that many metabolic enzymes that generate hydrogen peroxide as a by-product are sequestered here because peroxides are toxic to cells. Within peroxisomes, hydrogen peroxide is degraded by the enzyme catalase to water and oxygen.

Peroxisomes are surrounded by a single membrane and they range in the diameter from 0.1 to 1 mm. They exist either in the form of a network of interconnected tubules (peroxisome reticulum) as in liver cells or as individual micro peroxisomes in other cells such as tissue culture fibroblasts.

Peroxisome Structure

Peroxisomes vary in shape, size and number depending upon the energy requirements of the cell. These are made of a phospholipid bilayer with many membrane-bound proteins.

The enzymes involved in lipid metabolism are synthesised on free ribosomes and selectively imported to peroxisomes. These enzymes include one of the two signalling sequences- Peroxisome Target Sequence 1 being the most common one.

The phospholipids of peroxisomes are usually synthesised in smooth Endoplasmic reticulum. Due to the ingress of proteins and lipids, the peroxisome grows in size and divides into two organelles.

Peroxisome Function

The main function of peroxisome is the lipid metabolism and the processing of reactive oxygen species. Other peroxisome functions include:

- The synthesis of ether glycerolipids of plasmalogens.
- The formation of bile acids, dolichol, and cholesterol.
- The catabolism of purines, polyamines, and amino acids, and the detoxification of reactive oxygen species
- In methylotrophic yeasts, peroxisomes are also involved in the metabolism of methanol and methylamines.

In plants, peroxisomes facilitate photosynthesis and seed germination. They prevent loss of energy during **photosynthesis** carbon fixation.

Metabolism of Peroxisomes

Isolated peroxisomes are permeable to small molecules such as sucrose. During the isolation process, they often lose proteins that are normally confined to the peroxisomal matrix. In all living cells, peroxisomes are the sealed vesicles surrounded by a single membrane.

Biogenesis of Peroxisomes

As peroxisomes have no DNA, all their proteins must be imported from genes encoded in the nucleus. Most of the proteins that reside in the peroxisome matrix and membrane are synthesized in the cytosol and then imported posttranslationally to the organelle.

About 25 PEX genes, encoding proteins called peroxins are necessary for the biogenesis of the organelle. Most of these genes are found in multiple organisms and 13 are conserved in humans.

MORPHOLOGY AND FUNCTIONS OF GLYOXYSOMES,

Glyoxysomes are specialized peroxisomes found in plants (particularly in the fat storage tissues of germinating seeds) and also in filamentous fungi. Seeds that contain fats and oils include corn, soybean, sunflower, peanut and pumpkin.[1] As in all peroxisomes, in glyoxysomes the fatty acids are oxidized to acetyl-CoA by peroxisomal β-oxidation enzymes. When the fatty acids are oxidized hydrogen peroxide (H_2O_2) is produced as oxygen (O_2) is consumed.[1] Thus the seeds need oxygen to germinate. Besides peroxisomal functions, glyoxysomes possess

additionally the key enzymes of glyoxylate cycle (isocitrate lyase and malate synthase) which accomplish the glyoxylate cycle bypass.

Thus, glyoxysomes (as all peroxisomes) contain enzymes that initiate the breakdown of fatty acids and additionally possess the enzymes to produce intermediate products for the synthesis of sugars by gluconeogenesis. The seedling uses these sugars synthesized from fats until it is mature enough to produce them by photosynthesis.

Plant peroxisomes also participate in photorespiration and nitrogen metabolism in root nodules.

MORPHOLOGY AND FUNCTIONS OF PLANT CELL VACUOLES.

- A vacuole is a membrane-bound organelle that is present in all plant and fungal cells and some protist, animal and bacterial cells.
- The most conspicuous compartment in most plant cells is a very large, fluid-filled vacuole. Large vacuoles are also found in three genera of filamentous sulfur bacteria, the *Thioploca*, *Beggiatoa*, and *Thiomargarita*.
- However, the function and significance of vacuoles vary greatly according to the type of cell having much greater prominence in the cells of plants, fungi, and certain protists than those of animals and bacteria.
- There may be several vacuoles in a single cell. Each vacuole is separated from the cytoplasm by a single unit membrane, called the tonoplast.
- Generally, they occupy more than 30 percent of the cell volume; but this may vary from 5 percent to 90 percent, depending on the cell type.

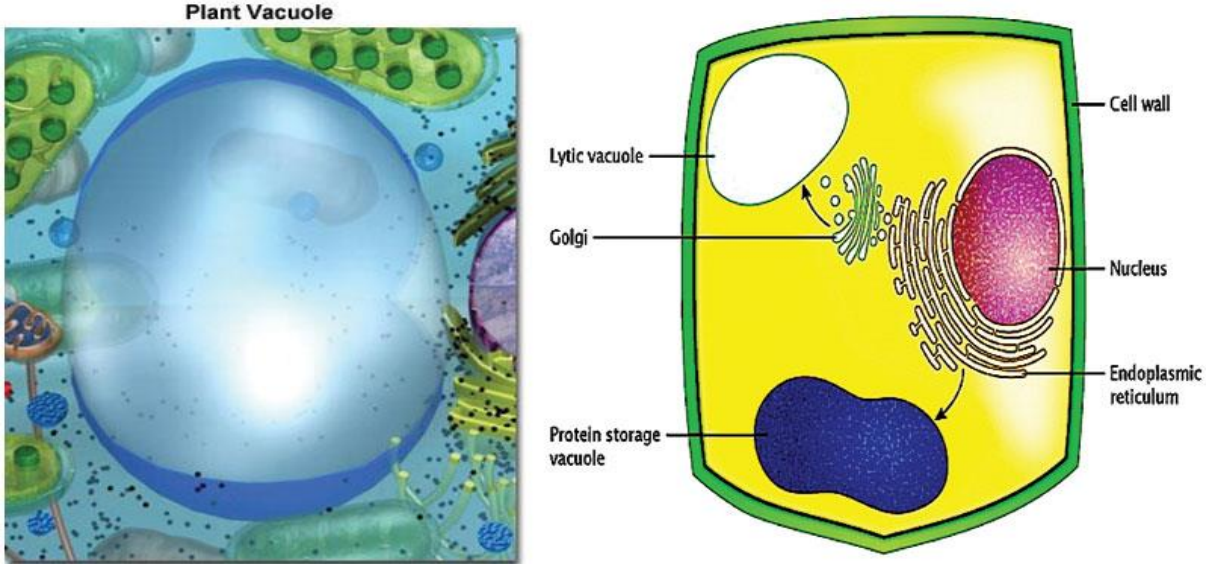

Figure: Diagram of Vacuoles

Structure of Vacuoles

- They generally have no basic shape or size; its structure varies according to the requirements of the cell.

- In immature and actively dividing plant cells the vacuoles are quite small. These vacuoles arise initially in young dividing cells, probably by the progressive fusion of vesicles derived from the Golgi apparatus.
- A vacuole is surrounded by a membrane called the tonoplast or vacuolar membrane and filled with cell sap.
- The tonoplast is the cytoplasmic membrane surrounding a vacuole, separating the vacuolar contents from the cell's cytoplasm. As a membrane, it is mainly involved in regulating the movements of ions around the cell, and isolating materials that might be harmful or a threat to the cell.
- Vacuoles are structurally and functionally related to lysosomes in animal cells and may contain a wide range of hydrolytic enzymes. In addition, they usually contain sugars, salts, acids and nitrogenous compounds such as alkaloids and anthocyanin pigments in their cell sap.
- The pH of plant vacuoles may be as high as 9 to 10 due to large quantities of alkaline substances or as low as 3 due to the accumulation of quantities of acids (e.g., citric, oxalic and tartaric acids).

Types

Sap Vacuoles:

- It has a number of transport systems for the passage of different substances. A number of small sap vacuoles occur in animal cells and young plant cells. In mature plant cells, the small vacuoles fuse to form a single large central vacuole which occupies up to 90% of the volume of the cell.
- The large central vacuole spreads the cytoplasm in the form of a thin peripheral layer.
- This is a device to facilitate rapid exchange between the cytoplasm and the surrounding environment. The fluid present in the sap vacuoles is often called a sap or vacuolar sap.

Contractile Vacuoles:

- They occur in some protistan and algal cells found mostly in freshwater.
- A contractile vacuole has a highly extensible and collapsible membrane. It is also connected to a few feeding canals (e.g., Paramecium). The feeding canals obtain water with or without waste products from the surrounding cytoplasm. They pour the same into the contractile vacuole.
- The vacuole swells up. The process is called diastole. The swollen contractile vacuole comes in contact with the plasma membrane and collapses. Collapsing is called systole. This throws the vacuolar contents to the outside.
- Contractile vacuoles take part in osmoregulation and excretion.

Food Vacuoles:

- They occur in the cells of protozoan protists, several lower animals and phagocytes of higher animals.
- A food vacuole is formed by the fusion of a phagosome and a lysosome. The food vacuole contains digestive enzymes with the help of which nutrients are digested. The digested materials pass out into the surrounding cytoplasm.

Air Vacuoles (Pseudo-vacuoles, Gas vacuoles):

- They have been reported only in prokaryotes.
- An air vacuole is not a single entity, neither it is surrounded by a common membrane. It consists of a number of smaller sub-microscopic vesicles. Each vesicle is surrounded by a protein membrane and encloses metabolic gases.
- Air vacuoles not only store gases but provide buoyancy, mechanical strength and protection from harmful radiations.

Functions

A plant vacuole has a variety of functions. Different vacuoles with distinct functions are also often present in the same cell.

- Plant vacuoles can store many types of molecules. It can act as a storage organelle for both nutrients and waste products.
- Some of the products stored by vacuoles have a metabolic function. For example, succulent plants open their stomata and take up carbon dioxide at night (when transpiration losses are less than in the day) and convert it to malic acid. This acid is stored in vacuoles until the following day when light energy can be used to convert it to sugar while the stomata are kept shut.
- In particular, they can sequester substances that are potentially harmful to the plant cell, if they are present in bulk in the cytoplasm.
- The vacuole has an important homeostatic function in plant cells that are subjected to wide variations in their environment. For example, when the pH in the environment drops, the flux of H+ into the cytoplasm is buffered by increased transport of H+ into the vacuole.
- Many plant cells maintain turgor pressure at remarkable constant levels in the face of large changes in the tonicity of the fluids in their immediate environment by changing the somatic pressure of the cytoplasm and vacuole—in part by controlled breakdown and resynthesis of polymers such as polyphosphate in the vacuole, and in part by altering
- By increasing in size, vacuoles allow the germinating plant or its organs (such as leaves) to grow very quickly and using up mostly just water.
- In seeds, stored proteins needed for germination are kept in ‘protein bodies’, which are modified vacuoles.

In Other Cells

- **In fungal cells**, they are involved in many processes including the homeostasis of cell pH and the concentration of ions, osmoregulation, storing amino acids and polyphosphate and degradative processes.
- **In animal cells**, vacuoles perform mostly subordinate roles, assisting in larger processes of exocytosis and endocytosis.

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SCHOOL OF BIO AND CHEMICAL ENGINEERING

DEPARTMENT OF BIOTECHNOLOGY

UNIT – V – CELL BIOLOGY – SBB1101

SBB1101	CELL BIOLOGY	L	T	P	Credits	Total Marks
		3	1	0	4	100

COURSE OBJECTIVES

- Cell biology is the study of the structure and function of prokaryotic and eukaryotic cells. In this course the students will learn different areas of cellular biology including the structure and functions of cell, its organelles, synthesis and function of macromolecules such as carbohydrate, protein, lipid, DNA & RNA; membrane structure and function; bioenergetics; cellular communication; and microscopic techniques to understand the cell structure.

UNIT 1 FUNDAMENTALS OF CELL STRUCTURE **12 Hrs.**

Discovery of cells; Basic properties of cells; Different classes of cells – Prokaryotic and eukaryotic cells. Cell division: Cell cycle; mitosis; meiosis, binary fission.

UNIT 2 CELLULAR MEMBRANES AND MATRICES **12 Hrs.**

Chemical composition and fluidity of membranes; dynamic nature of membranes; transportation across cell membrane; membrane potentials; extracellular matrices – structure and function; cytoskeleton – structure and function.

UNIT 3 CELLULAR ORGANELLES IN ENERGY METABOLISM **12 Hrs.**

Mitochondria – structure and function; Chloroplast – structure and function. Structure of nucleus – nuclear membrane, nucleolus, chromatin, structure of nucleic acids

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2. Lewin B. 2007. Genes IX. Oxford University Press, London.
3. Ajoy Paul. 2011. Textbook of Cell and Molecular Biology. Books and Allied Ltd.
4. Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. 2008. Molecular Biology of Cell. 6th Edition. Garland Science, Taylor & Francis group Publishers.
5. Harvey Lodish, Arnold Berk, S Lawrence Zipursky, Paul Matsudaira, David Baltimore, and James Darnell. 1995. Molecular Cell Biology. 3rd Edition. W.H. Freeman Publishers.

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SBB1101	CELL BIOLOGY	L	T	P	Credits	Total Marks
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Mitochondria – structure and function; Chloroplast – structure and function. Structure of nucleus – nuclear membrane, nucleolus, chromatin, structure of nucleic acids

UNIT 4 CELLULAR ORGANELLES IN METABOLISM **12 Hrs.**

Endoplasmic reticulum – smooth & rough; function of endoplasmic reticulum; Golgi complex – structure and function; Ribosomes – Types, structure and function; Morphology and functions of peroxisomes and glyoxisomes; Plant cell vacuoles.

UNIT 5 TRANSPORT ACROSS CELL MEMBRANE **12 Hrs.**

Passive and active transports, Permeases, Sodium -potassium pumps, Ca 2+ ATPase pump, ATP dependant proton pumps, co-transport, symport, antiport, Endocytosis and Exocytosis. Introduction to intra and extra cellular products of medicinal use.

Max Hours.60

Text Books

1. Freifelder D. 1985. Molecular Biology, Narosa Publishing House. New Delhi.
2. Lewin B. 2007. Genes IX. Oxford University Press, London.
3. Ajoy Paul. 2011. Textbook of Cell and Molecular Biology. Books and Allied Ltd.
4. Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter. 2008. Molecular Biology of Cell. 6th Edition. Garland Science, Taylor & Francis group Publishers.
5. Harvey Lodish, Arnold Berk, S Lawrence Zipursky, Paul Matsudaira, David Baltimore, and James Darnell. 1995. Molecular Cell Biology. 3rd Edition. W.H. Freeman Publishers.

END SEMESTER EXAMINATION QUESTION PAPER PATTERN

Max. Marks : 100 **Exam Duration : 3 Hrs.**

PART A : 10 questions of 2 marks each - No choice **20 Marks**

PART B : 2 questions from each UNIT of internal choice; each carrying 16 marks **80 Marks**

UNIT: 5

Passive and Active Transport, Sodium Potasssium Pumps, Ca 2+ATPase pump, ATP dependant proton pumps, co-transport, symport, antiport, Endocytosis and Exocytosis. Introduction to intra and extracellular products of medicinal use.

Passage of substances across bio membranes or cell membrane is brought about by the following methods:

A. Transport of Water:

(I) Osmosis:

Osmosis is the diffusion of water or solvent molecules through plasma membrane from low osmotic pressure to high osmotic pressure, i.e., from high water contents to low water content. Plasma membrane acts as a differential membrane permitting the movement of water molecules in and out retaining the metabolites.

B. Transport of Ions and Small Molecules:

(II) Passive Transport:

It is a mode of membrane transport where the cell does not spend any energy nor shows any special activity. The transport is according to concentration gradient. It is of two types, passive diffusion and facilitated diffusion.

(a) Passive Diffusion or Transport across Cell Membranes:

Here the cell membrane plays a passive role in the transport of substances across it. Passive diffusion can occur either through lipid matrix of the membrane or with the help of channels.

(i) Lipid Soluble Substances:

It was found out by Overton (1900) that lipid soluble substances pass rapidly across the cell membrane according to their concentration gradient. Based on this finding, Overton proposed that cell membranes are made of lipids.

(ii) Channel Transport:

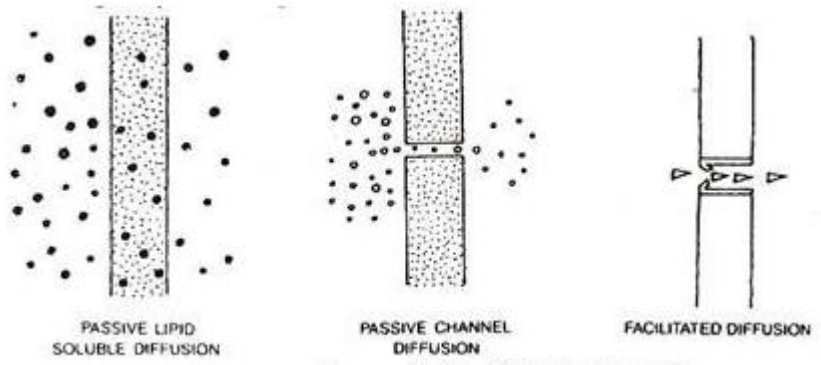
Membrane possesses channels in the form of tunnel proteins which do not carry any charge. They allow water and soluble gases (CO_2 and O_2) to pass according to their concentration gradient. Osmosis is an example of such a transport.

If two solutions of different concentrations are separated by a semi-permeable membrane, the solvent molecules move across the membrane from the less concentrated into the more concentrated solution. This process- the diffusion of solvent molecules into a region in which there is a higher concentration of solute to which the membrane is impermeable, is called osmosis.

Filtration is diffusion under pressure across a membrane having minute pores. Ultra filtration occurs during glomerular filtration inside kidneys. Dialysis is the process of separating small particles (e.g., crystalline solutes) from larger ones (e.g., colloids) due to difference in the rate of diffusion across a membrane having very minute pores.

(b) Facilitated Diffusion:

It occurs through the agency of special membrane proteins called permeases. When such carrier-mediated transport is from an area of greater concentration, energy is not required and the process is called facilitated diffusion. As a result, the rate of transport is stereo-specific.



Modes of Passive Transport.

Entry of glucose into red blood corpuscles is a facilitated diffusion.

The process of facilitated diffusion involves following steps:

1. Diffusing molecules combine with the specific carrier protein molecules forming carrier-protein complexes.

2. The shape of carrier protein molecule changes in response to the diffusing molecule so that the membrane – bound carrier protein complexes form, channels.

3. The shape of carrier protein molecule changes in response to diffusing molecule, allowing the molecule to cross the plasma membrane.

4. Once the diffusing molecule has reached the other side, the change in shape of carrier molecule (conformational change) lowers its affinity with the diffusing molecule, and allows it to be released.

5. After the release of diffusing molecule, the carrier-protein molecule resumes original shape.

The facilitated diffusion enables molecules to cross the otherwise impermeable or poorly permeable membrane.

Facilitated diffusion differs from simple diffusion in following features:

(i) Facilitated diffusion is stereo-specific (either L or D isomer is transported).

(ii) It shows saturation kinetics.

(iii) Facilitated diffusion requires a carrier for transport across the membrane. The carrier protein molecules move to and fro across the membrane by thermal diffusion.

(III) Active Transport:

It is uphill movement of materials across the membranes where the solute particles move against their chemical concentration or electro-chemical gradient. This form of transport requires energy which is provided almost exclusively by hydrolysis of ATP.

Active transport occurs in case of both ions and non-electrolytes, e.g., salt uptake by plant cells, ions, glucose and phenolphthalein in case of renal tubules, sodium and potassium in case of nerve cells, etc. It is supported by various evidences:

(a) Absorption is reduced or stopped with the decrease in oxygen content of the surrounding environment.

(b) Metabolic inhibitors like cyanides inhibit absorption.

(c) Cells often accumulate salts and other substances against their concentration gradient.

(d) Active transport shows saturation kinetics that is, the rate of transport increases with increase in solute concentration till a maximum is achieved. Beyond this value the rate of membrane transport does not increase indicating that it takes place through the agency of special organic molecules called carrier molecules, carrier particles or carrier proteins.

The carrier molecules are ATP ases, enzymes that catalyze the hydrolysis of ATP. The most important of these ATPases is Na^+-K^+ ATP ase which is also known as the Na^+-K^+ pump. There are in addition H^+-K^+ ATPases in the gastric mucosa and the renal tubules.

There is a special carrier molecule for each solute particle. The carrier has its binding site on two surfaces of the membrane. The solute particles combine with the carrier to form carrier-solute complex. In the bound state the carrier undergoes a conformational change which transports the solute to the other side of the membrane. Energy is used in bringing about the conformational change in the carrier. It is provided by ATP. In the process ATP is dephosphorylated to form ADP. Carrier proteins are of three types.

1. Uniport:

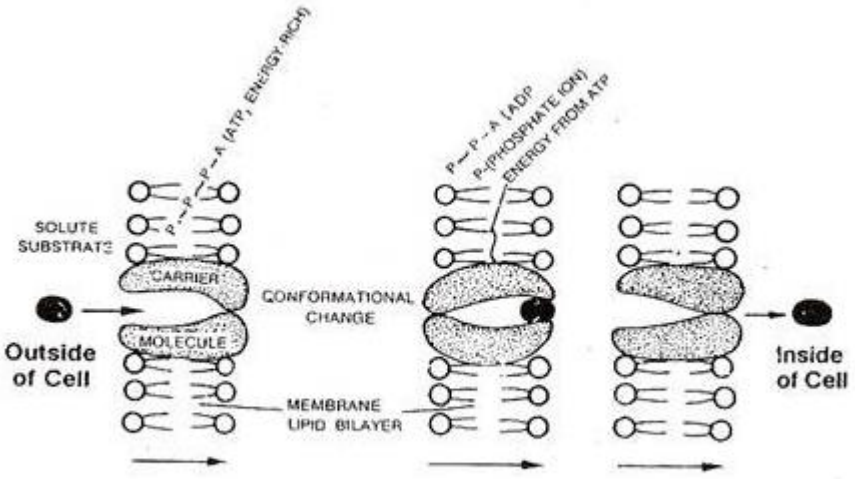
They transport only one substance.

2. Symports:

In some cases, transport requires the binding of more than one substance to the transport protein and the substances are transported across the membrane together. An example is the symport in the intestinal mucosa that is responsible for the co-transport by facilitated diffusion of Na^+ and glucose from the intestinal lumen into mucosal cells.

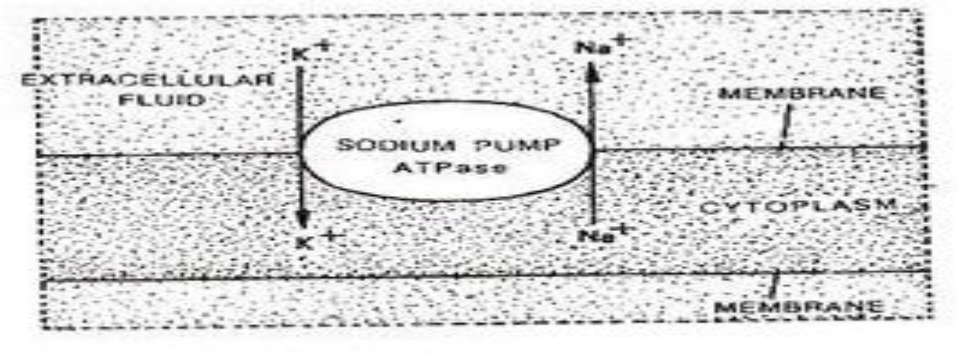
3. Antiports:

They exchange one substance for another. The Na^+-K^+ ATPase is a typical antiport.



Active transport across the membrane through a carrier molecule.

Many animal cells operate a sodium-potassium exchange pump at their plasma membrane. A similar proton pump operates in chloroplasts, mitochondria and bacteria Na^+—K^+ exchange pump operates with the help of enzyme ATP-ase which also functions as a carrier molecule.



Sodium potassium pump.

The enzyme hydrolyses ATP to release energy. The energy is used in bringing about conformational changes in the carrier. For every ATP molecule hydrolysed, three Na^+ ions are pumped outwardly and two K^+ ions are pumped inwardly.

Na^+– K^+ exchange pump performs the following functions: (i) Maintains a positive potential on the outer side of the membrane and relatively electronegative potential on the inner side,

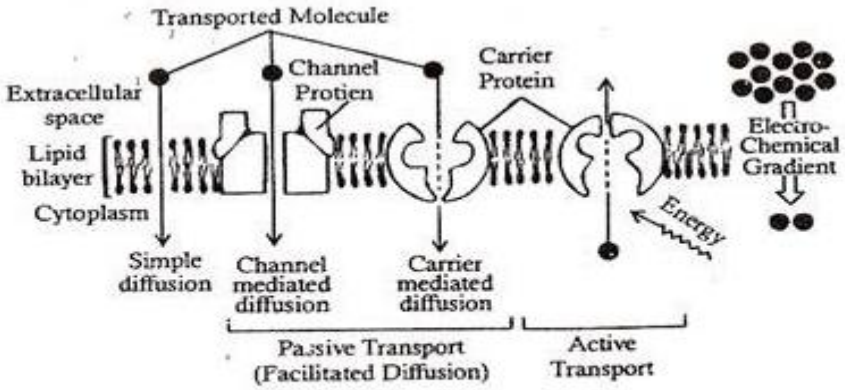
(ii) The pump creates a resting potential in the nerve cells,

(iii) The pump maintains water balance of living cells.

(iv) It helps in urine formation,

(v) It takes part in excretion of salt as in marine animals. Sea gulls and penguins drink sea water. They excrete excess salt through nasal glands. The nasal salt glands have sodium-potassium pump in the plasma membranes of their cells. Na^+ ions are pumped out actively. Chlorine ions pass out passively. Nasal secretion of the two birds possesses 1.5—3.0 times more NaCl concentration than the one present in the blood.

(vi) The unsecreted and unmetabolised excess Na^+ ions present in the extracellular fluid have a tendency to pass back into the cells. Other substances combine with sodium ions and pass inwardly along-with them, e.g., glucose, amino acids in intestine. The phenomenon is called secondary active transport as compared to Na^+—K^+ exchange pump which is called primary active transport.



Different methods of transport of substances through biological membrane. (Simple diffusion, channel mediated diffusion, carrier mediated diffusion and active transport).

Other important pumps include Calcium pump (RBCs, muscles), K^+ pump, CP pump, K^+—H^+ exchange pumps. The last one occurs in guard cells.

Active transport is a means of (i) absorption of most nutrients from the intestine (ii) reabsorption of useful material from the uriniferous tubules (iii) rapid and selective absorption of nutrients by cells (iv) maintaining a membrane potential (v) maintenance of resting potential in nerve cells (vi) maintaining water and ionic balance between cells and extracellular fluid, (vii) excretion of salt glands.

C. Transport of Solid Particles (Bulk transport):

Bulk transport inwards as well as outwards occurs across the plasma membrane by invagination and evagination of the membrane. Bulk transport is useful in carrying large molecules which would have difficulty in passing through the cell membrane normally. Endocytosis and exocytosis are the two ways in which bulk transport is accomplished.

(IV) Endocytosis is the process of engulfing large sized particles of food substances or of foreign substances. According to the nature of substances, the endocytosis may be:

(i) Pinocytosis or cells drinking is the process of intake of fluid material by the cell.

(ii) Micro pinocytosis is the pinocytosis of subcellular or sub microscopic level.

(iii) Rhophaeocytosis is the transfer of small quantities of cytoplasm together with their inclusion.

(iv) Phagocytosis is engulfing of large sized particles of solid food or solid matter by the cell.

(V) Exocytosis is the process of exudating the secretary products to outside the cell cytoplasm. It is also known as emeicytosis or cell vomiting. In cells of pancreas, the vacuoles containing enzymes move from the interior of the cytoplasm towards the surface. Here they fuse with plasma membrane and discharge their contents to the exterior.