COURSE OUTLINE

BIO 111 Cell Biology 2 Credits

Cellular basis of life/cell theory. History of microscopy, Schleiden & Schwann Structure and ultra-stuctureof plant and animal cells. (Typical/ generalised cell) Functions of cells and cellular organelles. Specialised & un-specialised cells. Animals:- epithelial cells, muscle cells, bone cells, nerve cells, blood cells e.t.c. Plant cells:- meristematic cell, parenchyma, chlorenchyma, chollenchyma, sclerenchyma, sieve tube & companion cell, vessel element, e.t.c. Cell division, Heredity.

WEEK 1

WHAT IS A CELL?

A cell may be defined as the basic structural and functional unit of a living organism. All living organisms are composed of cells just as all matters are composed of atoms. A cell is fundamental unit of life just as an atom is the basic unit of all physical matters. As the atom is composed of several constituents such as electron, proton, neutron, etc. the cell is also made up of various cellular components (cell organelles) such as mitochondria, ribosomes, Golgi bodies, lysosomes, endoplasmic reticulum, peroxisomes, etc. As an atom consists of a nucleus, most cells possess a nucleus suspended in cytoplasm.

BRIEF HISTORY OF CELL BIOLOGY'

Robert Hooke (1635-1703) was the first to observe an array of tiny pore-like structures (cell-like structures) in a piece of cork (a plant tissue) with the help of his self-made primitive type of microscope in 1665, and named them cells'.
In 1676, **Antony van Leeuwenhock (1632-1732)**, a Dutch lens grinder, observed a variety of living unicellular organisms with the help of his self-assembled microscope and called them '**animalcules'**. Now it is well known that those 'animalcules' were bacteria, protozoa and other 'unicellular microorganisms'. In 1833, **Robert Brown** observed a distinct structure suspended in each cell and named it **'nucleus'.**
On the basis of these observations and findings of several other workers, the German scientists, **M.J. Schleiden (1804-1881)**, a botanist, and **T. Schwann (1810-1882)**, a zoologist, proposed their famous 'Cell theory' in 1838.
According to cell theory, 'cells are the structural and functional units of living organisms' (both plants and animals).
In 1859, **Rudolf Virchow (1821-1902)**, a German physician, further modified the theory that (i)
All living organisms are composed of cells and products of cells and
(ii) 'new cell must necessarily be derived from pre-existing cells'.
After **Schleiden** and **Schwann** and **Rudolf Virchow's** observations, much more information has been added to the knowledge of cell structure and function, particu¬larly after invention of compound microscope (1710), ultra-microscope (1900), electron microscope (1932), phase-contrast microscope (1940), reflecting

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microscope (1943) and fluorescence microscope (1945).

WHY STUDY CELL STRUCTURE AND FUNCTION?

The answer is most of the biochemical reactions and physiological functions necessary for life, i.e. for normal development, metabolism and function of body, take place within the extremely small dimensions of all living cells. In living cells, the biochemical reactions occur in different cellular compartments of microscopic volumes. These biochemical reactions take place in cytoplasm and different cell organelles like mitochondria, ribosomes, Golgi bodies, peroxisomes, lysosomes, etc. For example, glycolysis and tri-carboxylic acid cycle (TCA) take place in cytoplasm and mitochondria, respectively. The steps of urea cycle take place both in cytoplasm and mitochondria and β-oxidation of fatty acids occurs in mitochondria. The protein synthesis takes place on ribosomes and rough endoplasmic reticulum. Golgi bodies participate in synthesis, "post-translational modification, 'package' and 'secretion of proteins'.

Types of cells: Prokaryotic and Eukaryotic cells

There are two categories of cells-the prokaryotic cells (also known as prokaryotes) containing no 'well defined nucleus" and eukaryotic cells (also known as eukaryotes) containing "well defined true nucleus". The terms prokaryotic and eukaryotic have been derived from Greek word (Greek: *pro* means before. *Eu* means true and *karyon* means nucleus). The term prokaryotic means 'before nucleus' and eukaryotic means 'true nucleus'.

(i) *Prokaryotic cells:* Prokaryotes are
simple,
small (1 -10 µm in size) and
primitive type of cells (Fig. 1.3).
Prokaryotic cells consist of:
No 'well-defined nucleus' and
the genetic material is found scattered within the cytoplasm of cell.
These cells do not have membrane bound cell organelles such as:
mitochondria, Golgi bodies, lysosomes, peroxisomes, ER, etc.
Escherichia coli is the best known prokaryote.

(ii) Eukaryotic cells: As compared to prokaryotes, the eukaryotic cells are
highly developed;
relatively large (10-100 µm size) and
more complex in structure (Figs. 1.1).
Eukaryotes consist of '
well-defined true nucleus' surrounded by a
double layered nuclear membrane. In addition to nucleus,
the eukaryotic cells also consist of membrane bound cell organelles such as:
mitochondria, Golgi bodies, lysosomes. peroxisomes, ER, etc. A typical eukaryotic

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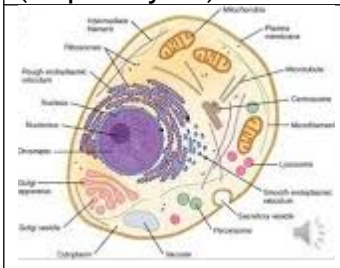
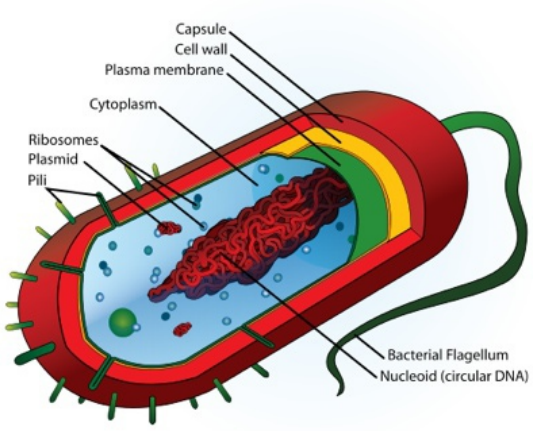
cell is always larger than a prokaryotic cell, for example, Hepatocytes (cells of the liver) have a diameter of 20 -30 µas compared to 1-2 µfor bacteria.

Eukaryotic cells are present in all multicellular organisms, both plants and animals. The unicellular micro-organisms such as protozoa, yeast, green algae, euglena etc. are Eukaryotes. Eukaryotic cells can be broadly grouped into plant and animal cells. Although both animal and plant cells have 'well defined nucleus'and membrane bound cell organelles, but they differ in structure.

Differences between Eukaryotic and Prokaryotic cells

Eukaryotic cell (Eu = true, Karyon = Nucleus)	**Prokaryotic cell** (Pro = Early/Primitive)
1. Nucleus distinct, with well formed nuclear membrane.	Nucleus not distinct, it is in the form of nuclear zone 'nucleoid'. Nuclear membrane absent.
2. Double-membraned cell organelles (Chloroplasts, mitochondria nucleus) and single membraned (Golgi apparatus, lysosomes vacuole endoplasm reticulum) are present	2. Single-membraned cell bodies like mesosomes present. Endoplasmic reticulum and golgi body absent
3. Ribosomes 80s	3. Ribosomes 70s
4. Distinct compartments in the cell i.e the cytoplasm and the nucleus.	No compartments
5. 1 – 10µm in size	5. 10 – 100µm in size
6. Example Plant or Animal cell. (Hepatocytes)	6. Example E. Coli
	
Eukaryotic cell	Prokaryotic cell
S is the coefficient of sedimentation of the ribosomes of Prokaryotic and Eukaryotic cells after the two cell membrane are broken by centrifuge.	

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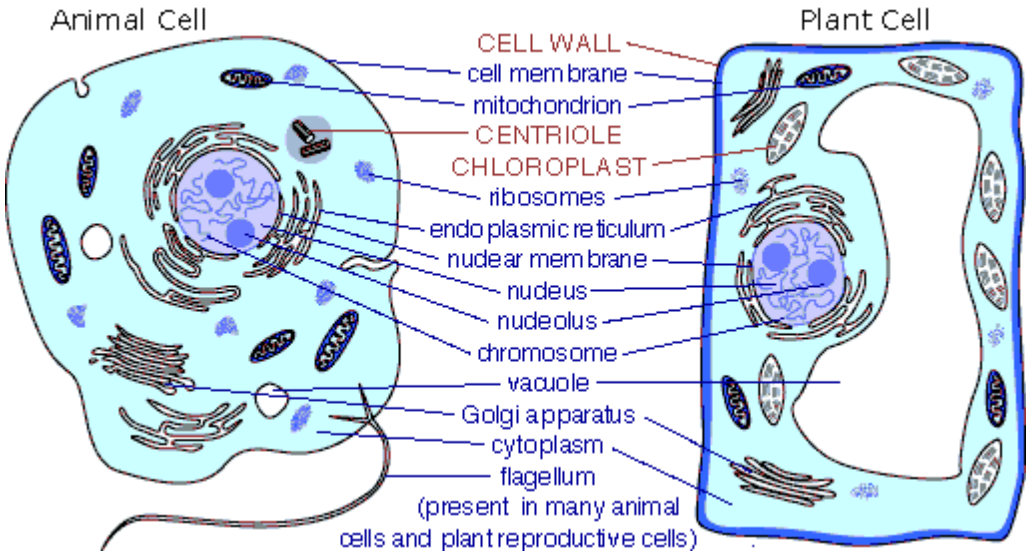
WEEK 2



DIFFRENCES BETWEEN A TYPICAL PLANT CELL AND AN ANIMAL CELL

CELL ORGANELLE	ANIMAL CELL	PLANT CELL
Cell Wall	Cell wall is Absent cytoplasm is bounded by cell membrane only.	Cell wall is present. Cytoplasm is bounded by cell membrane cell wall is made up of cellulose
Plastids	Plastids (chloroplasts) are absent	Plastids/chloroplast are present, because plants use chloroplasts to synthesize food.
Centrioles	Centrioles are present.	Centrioles are absent.
Lysosomes	Lysosomes are present	Lysosomes are absent
Vacoules	Normally found absent. If present is small.	Majority of plant cells have large vacoules that pushes cytoplasm to the side.
Flagella	Present	No flagella

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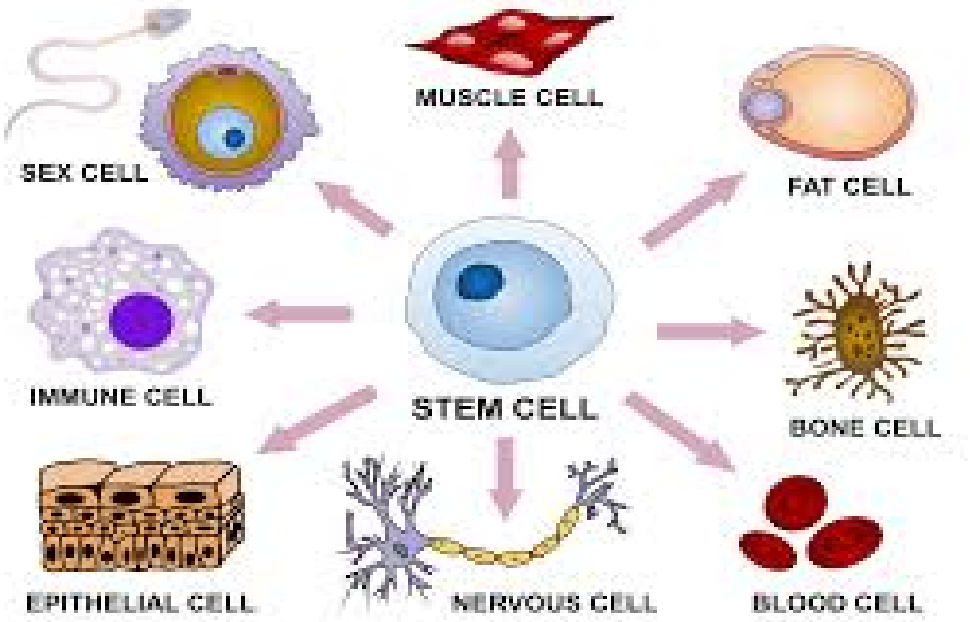
Shape and Size of Cells: Various kinds of cells present in human body exhibit a wide range of shape, size and other features (Fig, 1 .3**).** As far as shape is concerned, the cells can be divided in two main groups on the basis of their shapes.

(i) Cells with irregular and ever changing shape (Amoeboid type): These cells have ability to change their shapes, e.g. macrophages and white blood cells.

(ii) ***Cells with constant shape****:* Most of the cells in human body exhibit constant shape.

These cells may be spherical, cylindrical, columnar, oval, spindle, cuboidal, polygonal, flattened, rod-like, biconcave, rod shaped, cilia, micro-villi or flagella or thread-like in shape depending mainly on their functional adaptations (Fig, 1.3). The size of various kinds of cells present in human body generally varies from 10-100µ. The size of these cells may be 3-4µ (diameter of leucocytes) at one extreme and at other extreme it may be over a meter (length of neurons).



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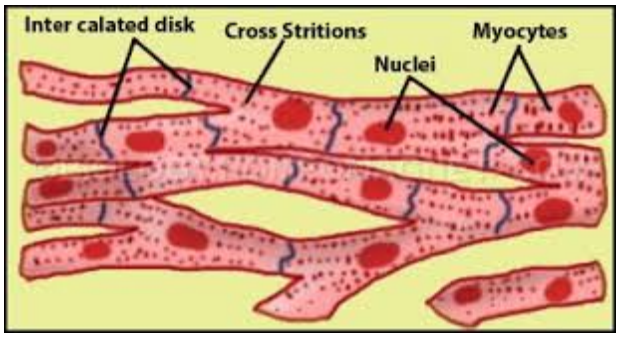

Cardiac cell

Ovum

Sperm cell

STRUCTURE AND FUNCTION OF VARIOUS CELLULAR COMPONENTS

Cell membrane (Plasma membrane):

1 Cell membrane (Plasma membrane)

Each cell has a limiting boundary, the cell membrane, plasma membrane or plasmalemma.
It is a living membrane, outermost in animal cells but next to cell wall in plant cells.
It is flexible and can fold in (as in food vacuoles of *Amoeba*) or fold out (as in the formation of pseudopodia of *Amoeba*)

The plasma membrane is made of proteins and lipids and several models were

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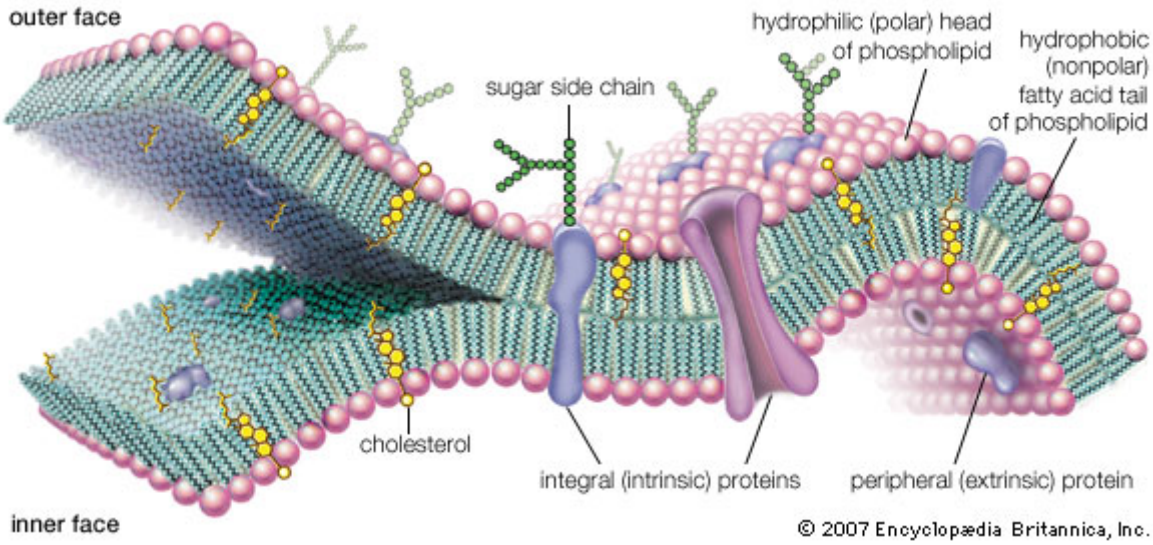
proposed regarding the arrangement of proteins and lipids. The **fluid mosaic model** proposed by Singer and Nicholson (1972) is widely accepted. It is represented in the figure below.



STRUCTURE OF THE PLASMA MEMBRANE

According to the fluid mosaic model,

(i) The plasma membrane is composed of a lipid bilayer of phospholipid molecules into which a variety of globular proteins are embedded.

(ii) Each phospholipid molecule has two ends, an outer head hydrophilic i.e. water attracting, and the inner tail pointing centrally hydrophobic, i.e. water repelling
(iii) The protein molecules are arranged in two different ways:
(a) Peripheral proteins or extrinsic proteins: these proteins are present on the outer and inner surfaces of lipid bilayer.
(b) Integral proteins or intrinsic proteins: These proteins penetrate lipid bilayer partially or wholly.

Functions:

(i) The plasma membrane encloses the cell contents.

(ii) It provides cell shape (in animal cells) e.g. the characteristic shape of red blood cells, nerve cells, bone cells, etc

(iii) Cell possesses various plasma membrane bound **receptors** for the physiological actions of vari¬ous hormones, neurotransmitters and drugs, e.g. adrenergic,

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cholinergic, glucagon, insulin, opioid receptors, etc.

(iv) Different mucoproteins of membranes of RBCs constitute the blood groups.

(v) It allows transport of certain substances into and out of the cell but not all substance, so it is termed selectively permeable.
Transport of small molecules (such as glucose, amino acids, water, mineral ions etc).
Small molecules can be transported across the plasma membrane by any one of the following three methods:

(i) **Diffusion** : molecules of substances move from their region of higher concentration to their region of lower concentration. This does not require energy. Example : absorption of glucose in a cell.

(ii) **Osmosis** : movement of water molecules from the region of their higher concentration to the region of their lower concentration through a semi-permeable membrane. There is no expenditure of energy in osmosis. This kind of movement is along concentration gradient.

(iii) **Active Transport** : When the direction of movement of a certain molecules is opposite that of diffusion i.e. from region of their lower concentration towards the region of their higher concentration, it would require an "active effort" by the cell for which energy is needed. This energy is provided by ATP (adenosine triphosphate). The active transport may also be through a carrier molecule.

Transport of large molecules (bulk transport)
During bulk transport the membrane changes its form and shape. It occurs in two ways:
(i) endocytosis (taking the substance in)
(ii) exocytosis (passing the substance out)
Endocytosis is of two types :

ENDOCYTOSIS

	Phagocytosis	Pinocytosis
1	Intake of solid particles.	Intake of fluid droplets.
2	Membrane folds out going round theparticle, forming a cavity and thus engulfing the particle.	Membrane folds in and forms a cup like structure sucks in the droplets.

Cell wall:
In bacteria and plant cells the outermost cell cover, present outside the plasma membrane is the **cell wall.**
Bacterial cell wall is made of peptidoglycan.

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Structure of the Cell wall:
– Outermost non-living, layer present in all plant cells.
– Secreted by the cell itself.
– In plant, it is made of cellulose but may also contain other chemical substance such as pectin and lignin.
– The substance constituting the cell is not simply homogenous but it consists of fine threads or fibres called microfibrils.
– It may be thin (1 micron) and transparent as in the cells of onion peel. In some cases it is very thick as in the cells of wood.

Functions:
– The cell wall protects the delicate inner parts of the cell.
– Being rigid, it gives shape to the cell.
– Being rigid, it does not allow distension of the cell, thus leading to turgidity of the cell that is useful in many ways
– It freely allows the passage of water and other chemicals into and out of the cells
– There are breaks in the primary wall of the adjacent cells through which cytoplasm of one cell remains conne cted with the other. These cytoplasmic strands which connect one cell to the other one are known as **plasmodesmata**.
– Walls of two adjacent cells are firmly joined by a cementing material called **middle lamella** made of calcium pectate.

WEEK 3

THE CYTOPLASM AND THE CELL ORGANELLES

The organelles found in the cytoplasm are grouped as thus:
1. Those that trap and release energy e.g. mitochondria and chloroplasts;
2. Those that are secretory or involved in synthesis and transport e.g. Golgi, ribosomes and endoplasmic reticulum
3. The organelles for motility - cilia and flagella
4. The ones associated with the destruction of worn out organelles: i.e. Lysosomes
5. The nucleus which controls all activities of the cell, and carries the hereditary material

Cell Organelles

A eukaryotic cell consists of various distinct membrane and non-membrane bound cell organelles and a double membrane bound nucleus suspended within the cytoplasm. The membrane bound cell organelles and nucleus are found absent in prokaryotic cells.

Membrane bound cell organelles: The structure and functions of various membrane bound cell organelles of eukaryotic animal cell are given below.

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Mitochondria:

Alls (except RBC's) contain mitochondria. Since mitochondria are the site of ATP synthesis, they are also called 'power house of cell'. The shape, size and number of mitochondria vary greatly depending on the type of cells and species.

Shape: The shape of mitochondria is greatly variable, from rod-shaped to spherical. Their shape may also be spiral, cylindrical, thread or filament like.

Number: Normally a typical cell has 500-800 mitochondria. However, the metabolically active cells like cardiac muscle fibre cells, neurons (axon terminals), etc. have large number of mitochondria. Some eukaryotic cells like sperm cells, yeast cells, etc. contain only a few large size mitochondria.

Structure of mitochondrion: Each mitochondrion is hollow sac-like structure filled with dense proteinous gel-like fluid called 'matrix' which is bounded by two unit membrane known as outer mitochondrial membrane (OMM) and inner mitochondrial membrane (IMM), each about 7 nm thick. The space between the two membranes is called peri-mitochondrion space The OMM is permeable to most metabolites and ions and is smooth at inner side, however, it may be rough at cytosolic side (i.e. at outer side) due to attached 80-S ribosomes. The IMM is selective permeable in nature and contains electron carrier proteins and ATP synthesizing system. IMM is internally folded into finger like structures known as cristae. The number of cristae var¬ies with the type of cells and their metabolic activities.

Structure of mitochondrion

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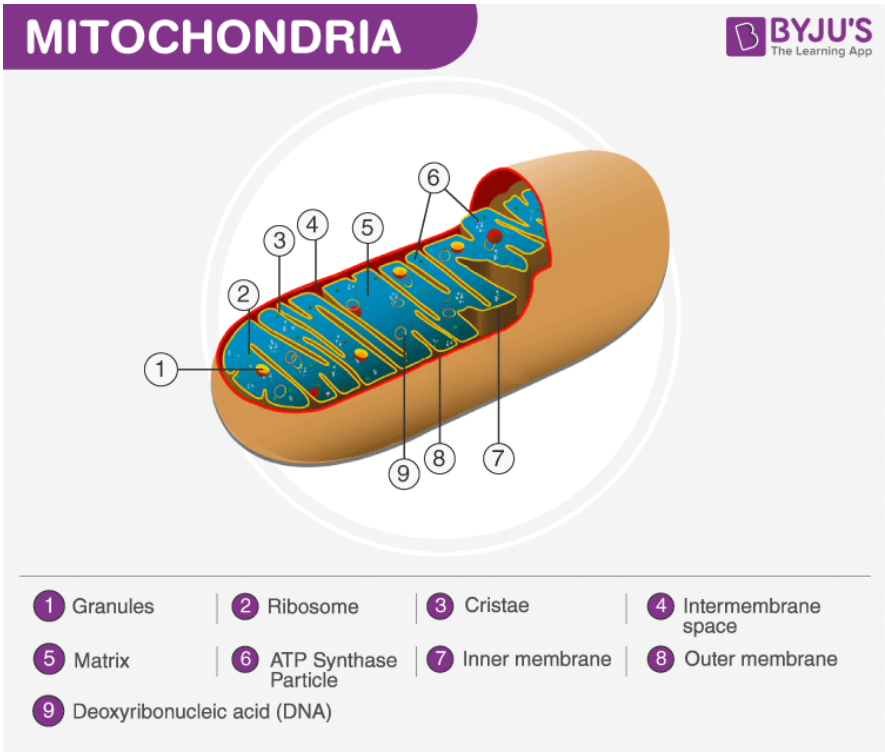

Functions of Mitochondria

1. Various biochemical reactions and metabolic pathways, e.g. **TCA** cycle, β - oxidation of fatty acids, ketogenesis, ketolysis, urea cycle, gluconeogensis. etc. occur in mitochondrial matrix.The enzymes of these pathways are present in mitochondrial matrix.

None Membrane Bound Organelles.

The structure and functions of various non-membrane bound cell organelles of an eukaryotic animal cell are as follows.

Functions of Ribosomes

Protein synthesis takes place on ribosomes, i.e. the genetic information contained in mRNA is translated on ribosomes to form polypeptide chain.

Endoplasmic reticulum (ER): All eu¬karyotic cells (except mature RBCs) contain ER. In smooth, skeletal and cardiac muscles, ER is also known as sarcoplasmic reticulum (SR).

ER is a three-dimensional network of tubular and sac-like cavities called cisternae bounded by a unit membrane. ER is distributed throughout the cytoplasm and also exists in con¬tinuity with the cell membrane and nuclear membrane (Fig. 1.2). ER

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develops profusely in grow¬ing cells, whereas it is distributed scantly in mature cells.

There are two types of ER: (i) Rough endoplasmic reticulum (RER) and (ii) Smooth endoplasmic reticulum (SER).

(i) Rough endoplasmic reticulum (RER): In RER, the Cytosolic (the side in contact with the cytoplasm fig 1.2 and 1.1a) membrane surface of ER is stud¬ded with ribosomes (Fig.1.1 & 1.2). The presence of ribosomes on the membrane surface of RER gives it a rough appearance.

RER is found in large amounts in cells actively involved in synthesis and secretion ('export) of proteins. For example, hepatic cells, pancreatic cells, β-lymphocytes cells are rich in RER and are actively involved in synthesis and 'secretion' of secretory proteins like plasma proteins, digestive enzymes, antibodies, respectively. The proteins synthesized on the ribosomes attached to RER are 'packaged' in 'secretory vesicles' and secreted or exported outside the cell with the help of Golgi bodies (Fig. 1.2).

(ii) Smooth endoplasmic reticulum (SER): The SER is not studded with ribosomes and has 'ribosome free' smooth membrane surface. SER is the site for biosynthesis of triglycerides (TGs), phospholipids, glycolipids, cholesterol and steroids. It is found abundantly in steroid hormone producing cells of testes, ovary and adrenal cortex.

FUNCTIONS OF ENDOPLASMIC RETICULUM

1) Network of ER divides the cytoplasm into many compartments and thus provides an additional mechanical support.

2) RER takes part in Synthesis', 'package' and 'export* of 'secretory proteins'.

3) SER takes part in biosynthesis of lipids (tri-glycerides, phospholipids, glycolipids and cholesterol) and steroid hormones.

4) SER of mammalian liver cells participates in detoxification reactions.

GOLGI BODIES (GOLGI APPARATUS):
Nearly all eukaryotic cells (except mammalian RBCs) are known to have Golgi bodies.

It is a collection of several membranous tubules (3-30 in numbers) and numerous membrane bound sacs like spherical vesicles (known as 'secretory vesicles'). These vesicles bud off from membranous tubules of Golgi bodies (Fig. 2.15). The Golgi bodies are suggested to be derived from ER. A number of individual Golgi body closely aggregate to form a 'Golgi complex'.

Presence of Golgi bodies is prominent in 'secretory cells' like hepatic cells, which are actively involved in 'export' ('secretion') of 'secretory proteins' such as plasma proteins (blood clotting proteins etc.) and digestive enzymes etc. The

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'secretory proteins' synthesized on the ribosomes of RER pass inside the lumen of the endoplasmic reticulum and are stored in membrane vesicles (transition vesicles). On transit to the Golgi body, these proteins undergo post-transitional modification in Golgi lumen (carbohydrate and lipid moiety are attached to the proteins to form **glycoproteins** and **lipoproteins**, respectively) and are 'packaged' into 'secretory vesicles'. These vesicles then fuse with the cell membrane at and release their contents outside the cell into extracellular space by exocytosis (Fig. 2.15). The 'secretory vesicles' also release their contents especially enzymes in internal cell organelles like lysosomes and peroxisomes. In addition to **glycoproteins** and **lipoproteins,** the Golgi bodies also take part in secretion of other substances such as **steroids, lipids, complex polysaccharides, etc.**

FUNCTION OF GOLGI BODIES

1. Golgi bodies are **'secretory cell organelles'.** They play important role in 'storage', 'package' and 'secretion of various secretory products.

2. Post-translational modification of proteins (addition of sugar and lipid moiety to protein molecules) occurs in Golgi lumen.

3. Golgi bodies give rise to primary lysosomes containing acid hydrolases.

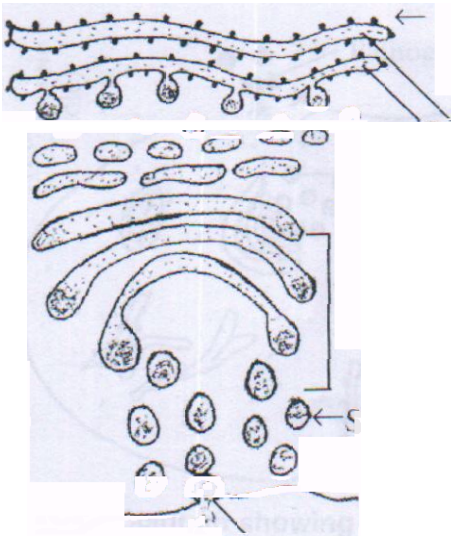

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Fig 2.15.diagram showing protein ‘synthesis’ its transport, ‘package’ and secretion by Golgi body

4. Golgi bodies and RER take part in synthesis and secretion of enzyme in lysosomes and peroxisomes.

5. The acrosome of sperm cell is derived from Golgi body.

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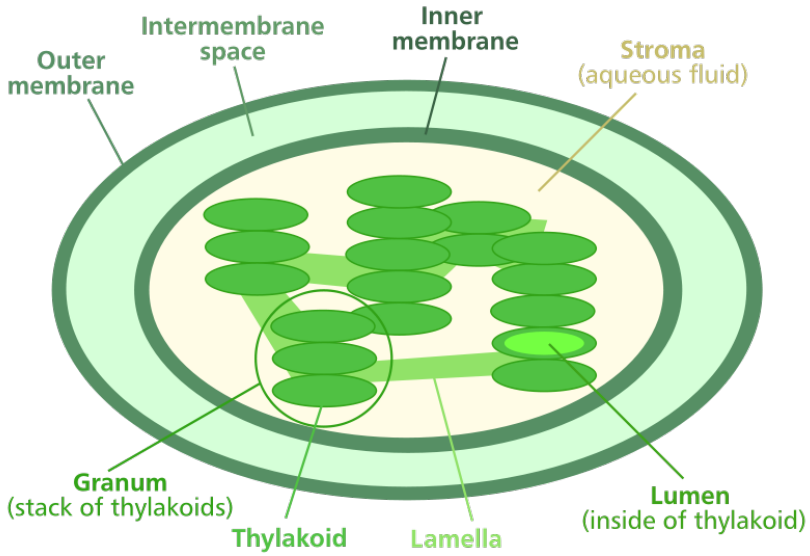

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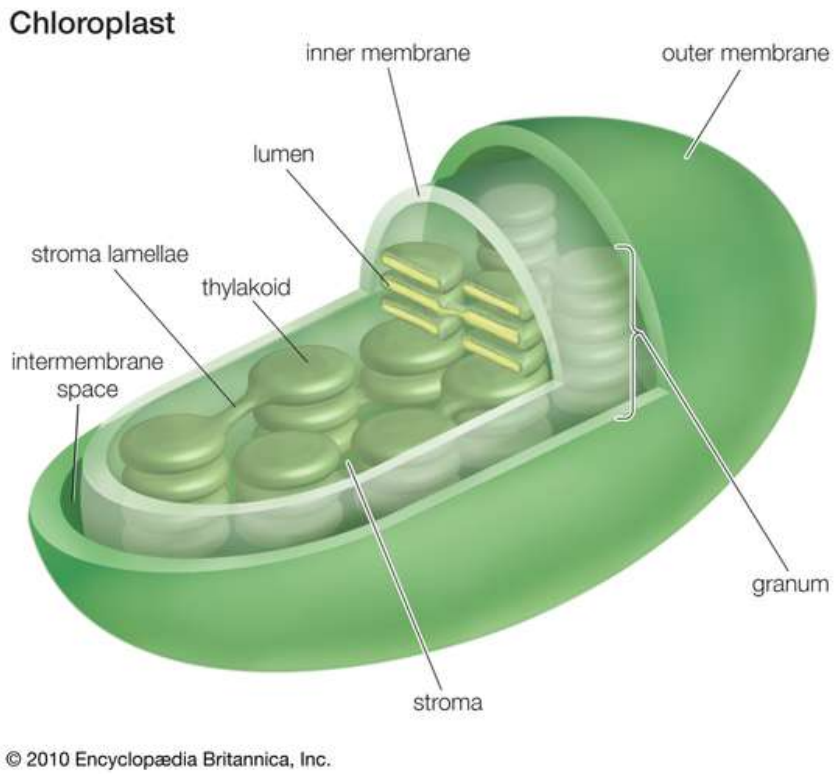

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Lysosomes:

Red blood cells (RBCs) and plant cells do not contain Lysosome. They are prominent in liver, spleen and renal cells, macro-phages and poly-morpho-nuclear (PMN) leucocytes.

Lysosomes are filled with powerful digestive enzymes. Enzymes like proteases, lipases, Carbohydrases are known to be present in the lysosomes. These digestive enzymes are capable of digesting essentially all biomolecules that are engulfed into the cell from outside during phagocytosis. These enzymes also digest the aging cell organelles ('worn out cell organelles') that are no longer required by the host cell, and the pathogens such as bacteria and virus that are engulfed into the cell during phagocytosis.

Function of lysosomes

1 **Heterophagy:** Lysosomal enzymes destroy the foreign substances and

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pathogens like bacteria and virus that are engulfed by the cells of immune system (macrophages and PMNs) and spleen.

2 Autophagy: Lysosomal enzymes also destroy aging cell organelles ('worn out cell organelles') that are no longer required by the host cell. Lysosomes are also capable of self-destruction of cell called autolysis, therefore, the lysosomes are also termed as 'suicide bags'.

Centrioles:

Centrioles, also known as centrosomes, were found only in animal cells. They are not present in plant cells (except fungal cells) and prokaryotes. Centrioles are arranged at right angles to each other.

Functions of centrioles:

1. Centrioles play very important role during cell division in animals. During cell division, they duplicate and a pair of centrioles moves to each pole of the cell. Each pair at opposite poles produces the spindle fibres (composed of microtubules), which radiate towards the equator of cell. The spindle fibres attach the chromosomes and help them to migrate towards both poles of the cell (Fig. 1.2).

2) Centrioles produce the basal bodies from which cilia and flagella develop.

Basal bodies, Cilia and Flagella.

Basal bodies: Centrioles divide to produce basal bodies. Similar to centrioles, a basal body is also composed 'triplets' of microtubules in "9+0" arrangement.

Cilia and flagella: Cilia (singular cilium) and flagella (singular flagellum) are hair-like, long (10-200 µm in length) and motile structures that originate from basal bodies present beneath the cell membrane. Cilia and flagella have same diameter but differ in length; cilia are shorter in length (about 10µm in length) than flagella (about 200 µm in length). Both cilia and flagella are composed of microtubules showing "9+2" arrangement and are surrounded by a unit membrane in continuation with cell membrane.

Functions:

1) Basal body is a structure to which a cilium or a flagellum is anchored.

2) Human sperm cells have a long flagellum (tail) which helps in locomotion. The ciliary and flagella movement requires cellular energy, which comes from hydrolysis of ATP.

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Cytoskeleton: In many animal cells, the non-membranous cell organelles namely **microtubules** and **microfilaments** constitute the cytoskeleton. Because of the cytoskeleton, many cells are capable of changing their shapes during endocytosis, exocytosis, muscle contraction-relaxation and locomotion. The cytoskeleton also participates in movement of cell organelles from one position to other within the cell.

Microfilaments: The microfilaments are long, non-membranous, non-tubular thin thread-like proteinous structures, e.g. neuro-filaments of neurons, tono-filaments of desmosomess and micro-filaments, in microvilli of intestinal epithelial cells.

Functions of microtubules and microfilaments

1) Being components of the cytoskeleton, both microfilaments and microtubules provide **mechanical support** and **give shape** to the cell.

2) Cell organelles namely basal bodies, centrioles, spindle fibers, cilia and flagella are composed of microtubules.

Nucleus: Nucleus was first of all discovered by **Robert Brown** (1833). It is a double membrane bound cell organelle. A 'true' nucleus is present in all eukaryotic cells except in mature human RBCs. It is the largest cell organelle, and can be seen under light-microscope. Typically, a cell has one nucleus, but some cells may contain more than one nucleus. Normally a nucleus is spherical in shape but in some cells it may be polymorphic, e.g. in WBCs. The nucleus is bi-lobed or multi-lobed. The living matrix of nucleus is called nucleo-plasm. IT is bounded at its outside by a double layered membrane known as nuclear membrane. The nucleus is characterized by the presence of several pores in nuclear membrane, known as nuclear pores. Various macromolecules such as hormones, rRNA, mRNA, polymerases, etc. can travel between cytoplasm and nucleus through these pores only.

Functions of Nucleus

1) Chromosomes present in nucleus are genetic material of the cell. Each chromo¬some is composed of giant a DNA molecule and basic protein, histone. Chro¬mosomes serve to store, express and trans¬fer the genetic information from one generation to other.

2) Nucleolus is the site of ribosomal RNA (rRNA) synthesis. rRNA is the structural and functional component of ribosomes.

3) Replication of DNA takes place in nucleus.

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CELL DIVISION:-

Reproduction involves the multiplication of cells. The formation of a bud in a simple animal like *Hydra,* the development of sex cells, and the growth of a young animal or plant into an adult all involve cell multiplication.

In order to multiply, cells undergo **cell division:** one divides into two, two into four, four into eight, and so on. The word division is misleading in some ways because it implies that the process always involves halving the cell and its contents. In fact we now know that cell division is accompanied or preceded by the formation of new cell components so that the products of cell division, the daughter cells, are essentially similar to the parent cell. Understanding cell division is largely a question of appreciating how this uniformity is preserved.

In any description of cell division the **chromosomes** occupy a central position. As the vehicles of heredity, they determine the characteristics of the cell and its

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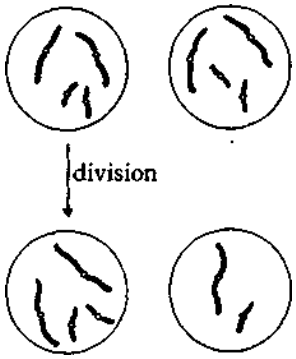
progeny, and it is essential that they should be correctly distributed between the daughter cells. It is known that a cell normally has a fixed number of chromosomes and these occur in pairs: the so-called **diploid** con¬dition. Two types of cell division are recognized according to the behavior of the chromosomes (Fig. 1). In the first of these, the daughter cells finish up containing exactly the same number of chromosomes as the parent cell. This is called **mitotic cell division** (or just **mitosis)** and is the type of cell division which takes place during an organism's growth. In the other type of division, known as **meiotic cell division** (or **meiosis)** the daughter cells finish up with half the total number of chromosomes present in the parent cell. This kind of division generally takes place in the formation of gametes, though in the more complex plantslater.



it occurs in the formation of spores. Its full implications will be discussed
Figure 1.
Mitosis
For purposes of description mitosis is divided into four stages: **Prophase, Metaphase, Anaphase and Telophase.** At each of these stages certain crucial events take place, particularly in regard to the chromosomes. However, it isimportant to realize that mitosis is a continuous process and there are; sharp breaks between one stage and the next. Typically the entire process takes about an hour and is followed by a **resting stage** (called **Interphase)** during which the daughter cells grow and prepare for the next division. This involves synthesis of new materials and replication of organelles. In actively dividing cells interphase lasts between 12 and 24 hours.

OBSERVING MITOSIS
One of the best places to see mitosis is the tip of a growing root, young bean roots for example. The root tip is cut off, sectioned or macerated, and treated with a dye such as acetic orcein which stains the chromosomes. In good preparations the various stages of mitosis can be clearly seen.

The endosperm tissue, the nutritive tissue surrounding the embryo inside seeds, to be almost ideal for observing cell division. Its cells divide prolifically and, and a rather

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soft runny tissue, a thin smear can be made on a microscope slide without harming the dividing cells.
Let us now follow what happens when a diploid cell undergoes mitotic vision. For convenience we will take a cell which happens to contain only four chromosomes: a pair of long ones and a pair of short ones. The events are summarized in Fig. 2, which should be consulted with the text.

INTERPHASE

During interphase (Fig .2A) the cell has the same appearance as any non-dividing cell. The chromosomes are not visible as distinct bodies either under the light microscope or the electron microscope. At this stage they are strung out in the form of long chromatin threads swollen at intervals into visiblechromatin granules. Not until prophase do the chromatin threads condense to form visible chromosomes.
To describe interphase as a resting stage is a complete misnomer. Far from being inactive the cell is growing and preparing for division. During interphase two things happen, both of which are essential if the cell is to divide. Firstly, the genetic material (DNA) replicates, i.e. doubles itself, so that sufficient DNAiS made available for each of the two daughter cells. A cell never divides until this new genetic material has been formed. Secondly, the cell builds up a sufficiently large store of energy, a kind of 'energy reservoir', to carry theprocess through. That this accumulation of energy takes place during interphase rather than during division itself can be shown by inhibiting respiration at different stages in mitosis. If a cell is treated with a metabolic poison such as cyanide during interphase, mitosis fails to take place. On the other hand if the cell is treated with poison after mitosis has started, the process will still go through to completion.

A third important event that takes place during interphase is the formation 'new cytoplasmic organelles - mitochondria, ribosomes, chloroplasts, and the like. If this did not happen successive cell divisions would result in a steady depletion of the cells' contents. Formation of new organelles takes place either by the production of new materials in the cytoplasm, or by the duplication of existing organelles. Either way, the synthetic activity involved necessitates the expenditure of much energy, and a high metabolic rate is typical of cells preparing for mitosis.
One of the most prominent organelles to replicate during mitosis is the centrioles. Found in the cells of all animals and certain primitive plants, the centrioles consist of a pair of short rods lying just outside the nuclear membrane. The cells of higher plants lack centrioles and yet undergo normal mitosis, so they are not essential for the process. However, in cells where they arepresent their movements are an integral part of the mitotic sequence. By interphase they have already replicated, so in Fig. 2A two pairs of centrioles are shown, one pair being destined to go into each daughter cell.

PROPHASE

If interphase is concerned with preparing the cell for division, prophase (Fig .2, C) can be described as 'mobilization for action'. Certain clearly visible events can be seen under the microscope. The most they gradually become shorter and fatter.

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As the chromosomes shorten it becomes increasingly clear that each consists of a pair of bodies lying close to each other. These are called **chromatids.** They tend to lie parallel along most of their length but are particularly closely associated in the vicinity of a specialized region called the **centromere.** We shall see later that this represents the centre of movement of the chromosome. The chromatids of one chromosome are usually referred to as **sister chromatids.** It is essential to appreciate what these chromatids represent. Initially (i.e. in early interphase) each chromosome consists of a single, highly attenuated thread. During replication of the genetic material an exact duplicate of this single thread is produced. The two threads together (the original one and its newly-formed duplicate) are completely invisible until prophase when they make their appearance as the two chromatids. The two chromatids making up a chromosome are identical: They contain exactly the same genetic material point for point along their length.

Condensation of the chromosomes is one of the most important events in prophase. If it failed to happen it would be impossible for the chromosomes to move around within the cell without getting tangled up. While this is happening other changes take place. A series of protein fibres are formed in the cytoplasm. These span the cell from end to end, forming a structure which, because of its appearance, is called the **spindle**. The two ends of the spindle are known as its **poles** and the middle region as its **equator.** In cells where centrioles are present, these now lie one at each of the two spindle poles. This is achieved by one of them skirting the nuclear membrane so that it comes to oc¬cupy a position at the opposite side of the nucleus. Meanwhile the nucleolus disappears. Prophase ends with the breakdown of the nuclear membrane.

METAPHASE

When the nuclear membrane disrupts the chromosomes migrate to the central plane of the cell and arrange themselves round the equator of the spindle (Fig.2, E). This is achieved through the organization of a series of fibres which run from the centromere of each chromosome to one of the two poles. At this moment the chromatids of each chromosome move slightly apart at the centromere region, the sister chromatids being orientated towards opposite poles as shown in Fig. 2E.

Fig.2 makes it quite clear that homologous chromosomes behave en¬tirely independently in the way they arrange themselves on the spindle. As far as is known they do not influence each other in any way, and they certainly do not associate with one another. Thus the two long chromosomes are at¬tached to different fibre systems, as are the two short chromosomes.

ANAPHASE

Suddenly the chromatids belonging to each chromosome part company and move towards opposite poles of the spindle. .

In recent years there has been much debate on the possible mechanism by which this migration of chromatids might take place. *It used to be thought* that the centromeres repel each other, causing the chromatids to move apart, but there is now evidence that the chromatids are pulled to the poles of the spindle. Observations on the spindle apparatus of live cells in the polarizing microscope have revealed two types *of spindle fibre (Fig 23.4). One type runs* right across the cell from

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one pole to the other; the other type runs from the poles to the centromere of each chromatid.
It is possible that the latter type of fibre shortens and pulls the chromatid, centromere' first, towards the pole. With the centromere in the lead, the rest of the chromatid will tend to trail behind. Energy is certainly required for this unique process. Mitochondria have been shown to congregate round the spindle apparatus, and chemical analysis of isolated spindles has shown them to contain an active enzyme which splits ATP.

TELOPHASE

The chromatids are destined to become the chromosomes of the daughter cells. On reaching the polar ends of the spindle they become densely packed together. Meanwhile the cell divides into two (Fig .2 H, I). In animal cells this takes place by means of a constriction of the plasma membrane which cuts across the equator of the spindle. In plants a new wall, the **cell plate,** grows across the middle of the cell: in root tip cells, where the spindle is about the full width of the cell, the plate is deposited as scattered droplets and vesicles which coalesce; in larger cells this is followed by expansion of the cell plate outwards until it fuses with the wall. While this is happening the spindle apparatus breaks down and the nuclear membrane is re -formed. The nucleolus reappears and the chromosomes gradually uncoil and return their original thread-like form. Mitosis is now complete; the daughter cells enter interphase and prepare for the next division.

THE ESSENTIAL PRINCIPLE UNDERLYING MITOSIS:- The really important thing about mitosis is that the daughter cells receive precisely the same number and types of chromo¬somes as the original parent cell: two long ones and two short ones in the ca.se described here. In other words the diploid constitution is maintained from one generation of cells to the next.
Two salient features of mitosis ensure that the chromosome constitution is preserved:
(1) The fact that the chromosomes of the parent cell replicate before the cell divides, and
(2) The arrangement of the chromosomes on the spindle.
As a result of replication of the chromosomes the parent cell in effect contains twice its normal number of its significance we must pause for a moment to consider the function of the gametes. By definition a gamete is a cell which cannot develop further until it fuses with another gamete. Thus a spermato¬zoon and an egg have no future unless they unite to form a **zygote** which then develops into an adult organism. In the process of fertilization the nuclei of the two gametes fuse to form the nucleus of the zygote. Now if the gametes were to have two of each type of chromosome, the zygote would obviously have four of each type, twice the normal number. Let us assume that this zygote develops into an adult which itself produces gametes with four of each type of chromosome. If two of these gametes were to unite, a zygote would be formed with eight of each type of chromosome, and so on. In other words if gametes were formed by mitosis rather than meiosis, the chromosome number would double with each succeeding generation. By halving the chromosome number meiosis ensures that this does not happen.

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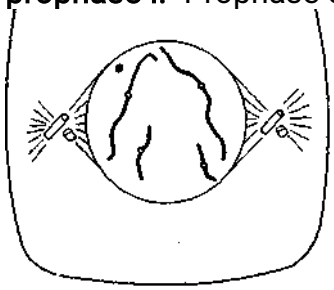
When gametes with the haploid number of chromosomes unite, the normal diploid condition is restored.
THE ESSENTIAL PRINCIPLE UNDERLYING MEIOSIS:-How does meiosis achieve this halving of the chromosome number? The answer lies in the behaviour of the chromosomes during prophase and metaphase. Meiosis consists of two successive divisions: the parent cell splits into two **(first meiotic division)** and the products then divide again **(second meiotic division),** giving a total of four daughter cells. In the first division homologous chromosomes get separated from each other and go into different cells. The second division is concerned with separating the chromatids.

With these basic ideas in mind let us examine in detail the events that take place in meiosis. As in mitosis the process is divided for convenience into a series of stages. These are given the same names as in mitosis but each is followed by I or II indicating whether it belongs to the first or second meiotic division.
prophase I:- Prophase one is divided into five deferent stages, thus:-



LEPLOTENE: at this early stage , the nucleus increase in size and the chromosomes appear as long slender and single threads diploid in number. The threads are present in exactly identical pairs one being paternal and the other maternal. They now begin to coil. In each thread there appear a number of small beadlike granules known as centrioles, which represents the tightest coils of the chromosomes.
Zygotene: it is seen that the identical chromosomes develop a strong affinity for each other, and they soon come together in pairs, part by part, throughout their whole length. This pairing is called synapsis, and every pair is called a bivalve. The pairing chromosomes are homologous.

Pachytene:-Pairing chromosomes becomes shorter due to their increased coiling. Each chromosomes split longitudinally and thus four chromatids (two from each homologue) are produced. The homologous chromosomes can be clearly identical at this stage.

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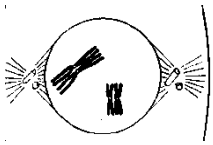
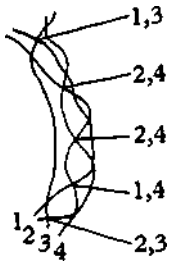
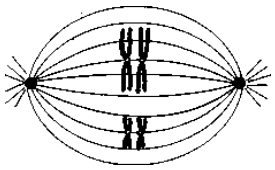


DEPLOTENE:-At this stage homologous chromosomes begin to separate from each other. However they remain connected at one or more points the chiasmata. At each chiasmata physical exchange of genetic materials takes place by crossing over. A special feature of meiosis.



DIAKINESIS:-At this stage the chromosomes bivalents move to the periphery of the nucleus and becomes separated from each other, except at the chiasmata. The chromosomes are thus released into the cytoplasm after the dissolution of the nucleolus and nuclear membrane.

METAPHASE1:- As in mitosis the chromosomes move to the equator of the spindle (Fig 23.6E). The important difference from mitosis is that here homologous chromosomes do this together; in other words each bivalent behaves as a unit. Moreover they arrange themselves in such a way that sister chromatids orientate towards the same pole, whereas the two homologous chromosomes orientate towards opposite poles. So the positioning of the chromosomes at this stage is quite different from what it is in mitosis. The cell is now poised ready for the separation of the homologous chromosomes.



ANAPHASEI:-The homologous chromosomes, each made up of a pair of chromatids joined at the centromere, move towards opposite poles of the spindle. The sister chro¬matids no longer remain in parallel alignment but diverge from one another.

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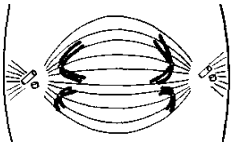
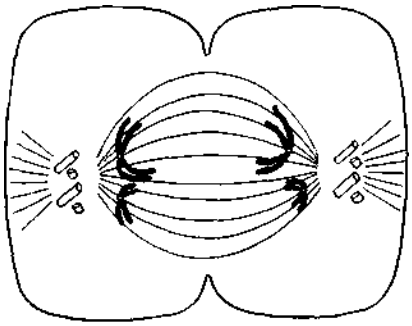


TELOPHASE I:- When the chromosomes reach their respective poles the cell generally divides across the middle as in mitosis. Usually the daughter cells go into a short resting state (interphase), but sometimes the chromosomes remain condensed and the daughter cells go straight into prophase of the second meiotic division.



THE SECOND MEIOTIC DIVISION:-Separation of homologous chromosomes has already been achieved by the first meiotic division, and the purpose of the second division is merely to separate the chromatids from one another. In prophase II anew spindle apparatus is formed. In metaphase II the chromosomes move to the equator of the spindle, the chromatids orientating towards opposite poles as in mitosis. Anaphase II sees the chromatids se¬parating and moving apart from each other. The chromatids become the chromosomes of the daughter cells. On reaching the poles the cell divides across the middle in the usual way (Telophase II). Characteristic of telophase, the spindle apparatus disappears, and the nucleolus and nuclear membrane are reformed. The chromosomes uncoil and regain their thread¬like form. Meiosis is complete: four cells (sometimes referred to as a **tetrad)** have been formed, and each cell has the haploid number of chromosomes.

From this brief description of meiosis it is clear that of the two successive divisions it is the first which is responsible for separating the homologous chromosomes and halving the chromosome number. For this reason the first meiotic division is described as a **reduction division.** The function of the second is to separate the chromatids from each other.

CHIASMATA:-As was mentioned earlier meiosis generally involves the formation of chias-mata**(chiasmate meiosis).** In the course of prophase I the intimate association • between homologous chromosomes weakens so that they move slightly apart. It can now be seen that the chromatids are attached to each other at certain points. These are the chiasmata. Chiasma formation is very varied. Every bivalent forms at least one chiasma, but in fact as many as eight may be present, and these can be formed between any two of the four

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chromatids (Fig 23.7). The chiasmata represent places where the chromatids may break and rejoin, a portion of one chromatid changing places with the equiv¬alent portion of another. This enables exchange of genes to occur between homologous chromosomes, a process known as **crossing over.** Since the two homologous chromosomes contain different genes, crossing over promotes genetic variety, which in turn plays an important part in the process by which evolution has taken place.

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