CYTOLOGY (CELL BIOLOGY)

Branch of Biology that deals with study of cells of organisms. A Cell is the fundamental / basic unit of life i.e. structure and function in living matter.

All organisms regardless of their size, are composed of cells. Some organisms consist of a single cell and are called unicellular e.g. bacteria, amoeba, paramecium. Other organisms are made up of many cells and are called multicellular organisms e.g. mammals and flowering plants.

The Cell theory

States that, "the basic unit of structure and function in living organisms is the cell". It was proposed jointly by two scientists namely schleiden, a Belgian botanist, (1838) and schwann, a German zoologist, (1839).

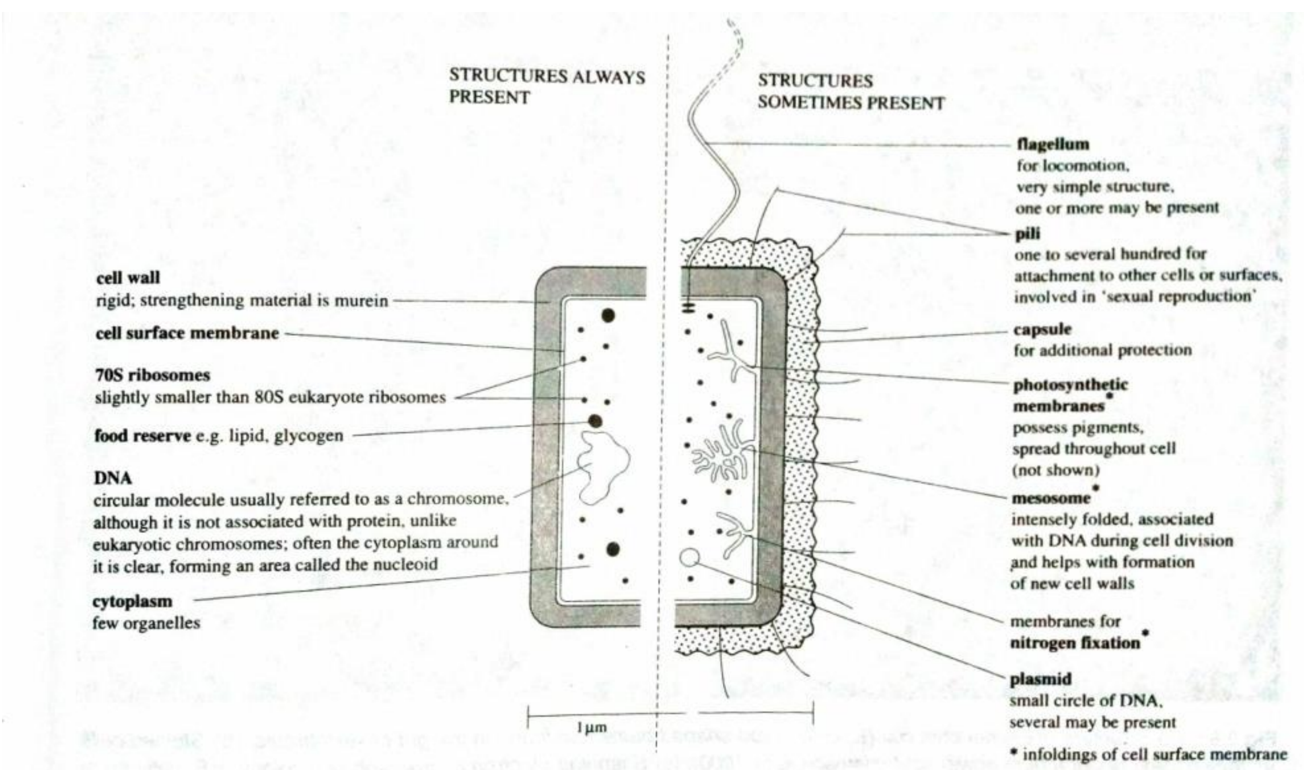
The modern **cell theory** sates that;

- ✓ All living organisms are composed of cell(s).
- ✓ All new cells are derived from pre - existing by division.
- ✓ Cells contain the hereditary material of an organism which is passed from parent to daughter cells during division.
- ✓ All metabolic processes takes place within cells.

Prokaryotes and Eukaryotes

Prokaryotic cells (pro 'before', karyo nucleus). Their hereditary material, DNA, is not enclosed within a nuclear envelope, lies free in the cytoplasm in a region known as **Nucleoid**. Hence there is no true nucleus. This absence of true nucleus only occurs in two groups, the bacteria and the blue green bacteria. There is no membrane bound organelles.

Structure of a generalized a rod shaped Bacterium (a typical prokaryote cell)



Eukaryotic cell (eu – 'true', karyo – 'nucleus'). Their DNA is inside nucleus, a structure surrounded by two membranes, the nuclear envelope. The DNA is also associated with proteins to form **chromosomes**.

Differences between prokaryotic and Eukaryotic cells.

Feature	Prokaryotic Cells	Eukaryotic Cells
Example	Bacteria and the blue green bacteria	Protoctists, Fungi, plants and animals
Cell size	Average diameter 0.5 – 10 µm ie smaller	10 – 100 µm i.e. much biggger
Form	Mainly unicellular	Mainly multicellular except protoctista.
Evolution	3.5 thousand million years ago	1.2 thousand million years ago
Nucleus	Absent ,have nucleoid	Present, has nuclear envelope
DNA	Circular and naked	Linear and with associated proteins.
Chromosomes	absent	present
Membrane bounded organelles	Absent	present
Ribosomes	are smaller, 70s	Are larger, 80s
Flagella	If present. Lack internal 9+2 fibril arrangement	Have 9+2 internal fibril arrangement.
Cell division	Mostly binary fission, no spindle	Mitosis and / or meiosis : spindle forms

Origin of Eukaryotic cells

Origin of Mitochondria and Chloroplasts Bacteria that live within other cells and perform specific functions for their host cells are called ***endosymbiotic*** bacteria. Their widespread presence in nature led Lynn Margulis to champion the ***endosymbiotic theory*** in the early 1970s.

The Endosymbiotic theory.

This theory suggests that, a critical stage in the evolution of eukaryotic cells involved endosymbiotic relationships where; larger ***anaerobic bacteria*** engulfed the smaller bacteria by the process of ***endocytosis,*** but digestion failed. Initially, the smaller bacteria could have lived inside larger bacteria either as ***parasites*** *or* ***phagocytic*** **vesicles,** after which a mutually benefitting relationship called ***endosymbiosis*** resulted, where the larger cell provided ***protection*** and ***shelter*** while the smaller organisms removed ***oxygen*** which was ***toxic*** to the anaerobic larger cell.

- ✓ Energy-producing bacteria may have come to reside within larger bacteria, eventually evolving into what we now know as ***mitochondria***.
- ✓ Similarly, photosynthetic bacteria may have come to live within other larger bacteria, leading to the evolution of ***chloroplasts***, the photosynthetic organelles of plants and algae
- ✓ Bacteria with flagella, long whiplike cellular appendages used for propulsion, may have become symbiotically involved with nonflagellated bacteria to produce larger, ***motile cells***.

NOTE; the fact that we witness so many symbiotic relationships lends general support to this theory.

Even stronger support comes from the observation that present-day organelles such as mitochondria, chloroplasts;

- ✓ Contain their ***own DNA***, which is remarkably similar to the DNA of bacteria in size and character.
- ✓ Reproduce by Binary fission like wise to prokaryotic cells.
- ✓ Have average diameter (0 – 10 µm) relative to that of bacteria.

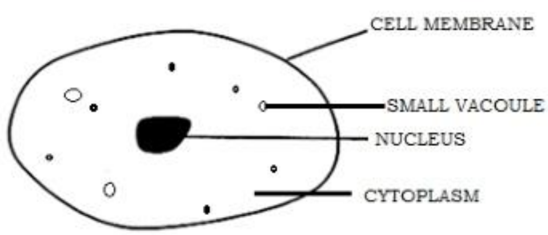
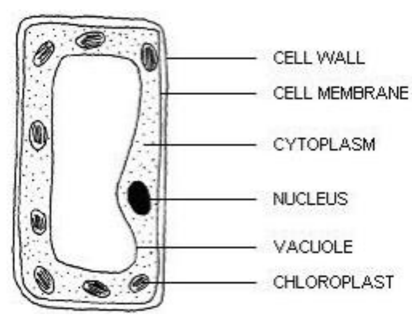
CELLS AS SEEN UNDER MICROSCOPE

Cells can't be seen by our naked eyes because are very small. Seen using a ***microscope***

There are two main types of microscopes;

- Light microscope
- Electron microscope

1. Light microscope; this uses a beam of light, its Cheap to operate, Can be used observe destruction of the specimen since specimens can be studied while intact, Uses cheap source of powder e.g. light.
BUT Has a low resolution (resolving power); not possible to investigate specimens I great details. And Low magnification power.

Animal cell as seen under Light Microscope	**Plant cell as seen under Light microscope**.
	

Qn. Generate differences between Animal cell and plant cell as seen under light microscope.

2. Electron microscope. The most common of this type of microscope is the transmission electron microscope (TEM). This uses a beam of electrons instead of light and electro - magnets instead of lenses.

The image is seen on a screen in form of a photograph called the ***electro micrograph.*** The electron beam from the electron gun is concentrated by the magnetic coil to pass through the specimen. The emerging electron pattern is focused and magnified by passing it through a series of electromagnetic.

The image is seen either on a fluorescent screen or recorded on a film. The whole instrument is enclosed in a high vacuum to prevent absorption or scattering of electrons by the gases in air.

Advantages

- Has a high resolving power because the wave length of the electron beam is by far smaller than that of light. The resolving power of TEM is 5000 times greater than that of a light microscope.
- It has a high magnifying power and this can be varied by altering the current supplied by the electro – magnets.

Disadvantages

- Since it requires that the specimen must be placed in a vacuum, the specimen can only be studied when dead or destroyed.
- Preparation of materials to be observed is lengthy (time consuming) and requires considerable experts and complex equipment.
- All images are in black and white
- Expensive to buy and operate.

Comparison of Light microscope and Electron microscope

Feature	Light microscope	Electron microscope
Radiation used	light rays	uses beams of electrons which require high voltages for generation
Radiation source	light bulb which only requires low voltage	electron gun
Specimen	Living or Non living	Nonliving, Dehydrated, relatively small or thin.
Common stains	Colored dyes	Contain heavy metals to reflect electrons.
Image	Usually colored	Black and white
Nature of lenses	glass to focus light rays	electromagnets which can deflect and thus focus electron beams
Lenses used	condenser, objective and eye piece lenses	condenser, objective and eyepiece lenses
Image viewed	directly by eye	a fluorescent (TV) screen is required
Mediation medium	air	a vacuum is required since electrons are easily scattered by particles in air
Magnification	up to X1500	up to X500,000
Max limit of resolution	200 nm	0.5 nm

3. **Scanning eletron microscope.**

This is a type of electron microscope where the image observed is obtained by studying the pattern of electrons reflected by the surface of the specimen. This provides a dimension image of the surface of specimen being studied.

Advantages

- Surfaces of structures are shown.
- Great depth of field, meaning that a large part of the specimen is in focus at the same time.
- Much larger samples can be examined than with a TEM.

Disadvantage

- Resolution (5 – 20 nm) is not as great as with a TEM {0.5nm)

Units of measurement

Units	Symbol	Fraction of a meter
Millimeter	mm	$X10^{-3}$
Micrometer	µm	$X10^{-6}$
Nanometer	Nm	$X10^{-9}$

Resolving power of a microscope

Is the ability off a microscope to distinguish between two different two objects that are very close as being separate. The electron microscope has a resolving power of about 0.5nm while that of light microscope is about 200nm.

Size and Magnification

Photomicrographs, electron-micrographs and biological drawings usually have either a statement of magnification (e.g. x100) or a linear scale of some description (a bar of defined length e.g. 50 nm).

Actual size can be determined using the following equation:

Actual size = (Image size) / (Magnification).

Magnification can be determined using the same relationship, rearranged as follows:

Magnification = (Image size) / Actual size.

EUKARYOTE CELLS AS SEEN BY ELECTRON MICROSCOPE

1. **ANIMAL CELL** This is made up of ;

a) Cell membrane.

b) Cytoplasm. Cytoplasm is composed of;

i) Cytosol, the fluid part of cytoplasm.,

ii) Cell organelles: An organelle is a distinct part of cell which has a particular structure and function.

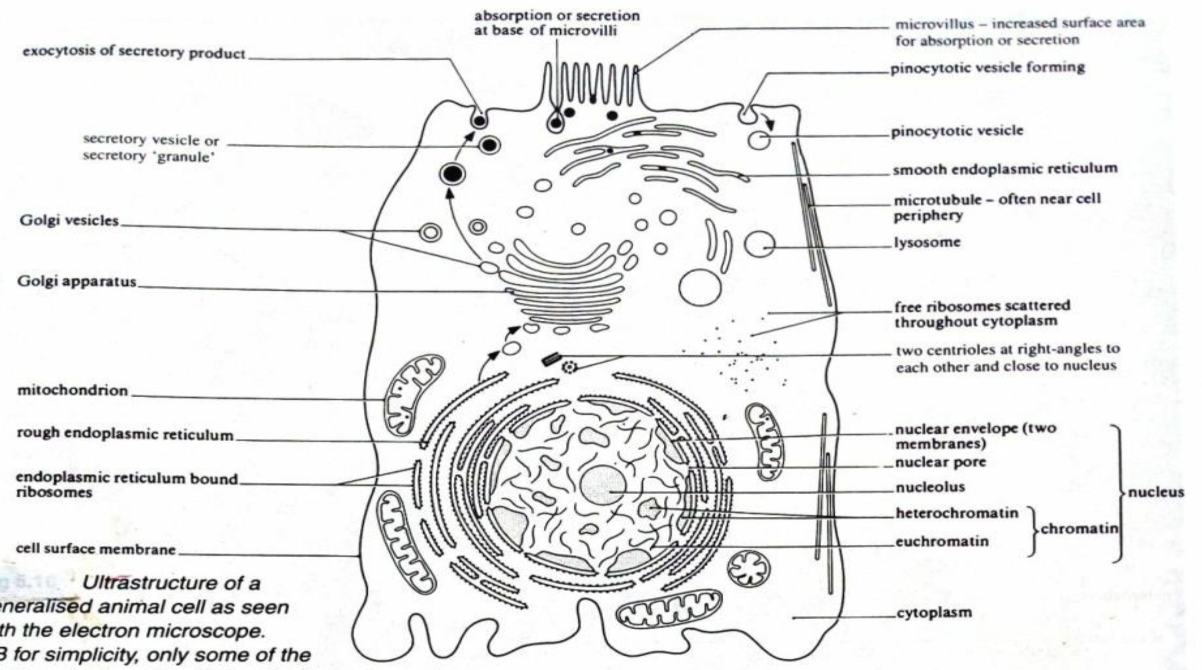
Examples of organelles in animal cell; Mitochondria (sing, mitochondrion), Golgi apparatus, Endoplasmic reticulum (smooth and Rough), Ribosomes (free of attached to ER), Lysosomes, Nucleus, Microtubules, Micro villi (sing, micro villus),

iii). Cytoplasmic inclusions. Insoluble, non-living substance suspended in the cytosol of a cell **not** capable of carrying out any metabolic activity. E.g. Glycogen granules, Fat droplets, Pinocytic Vesicles.

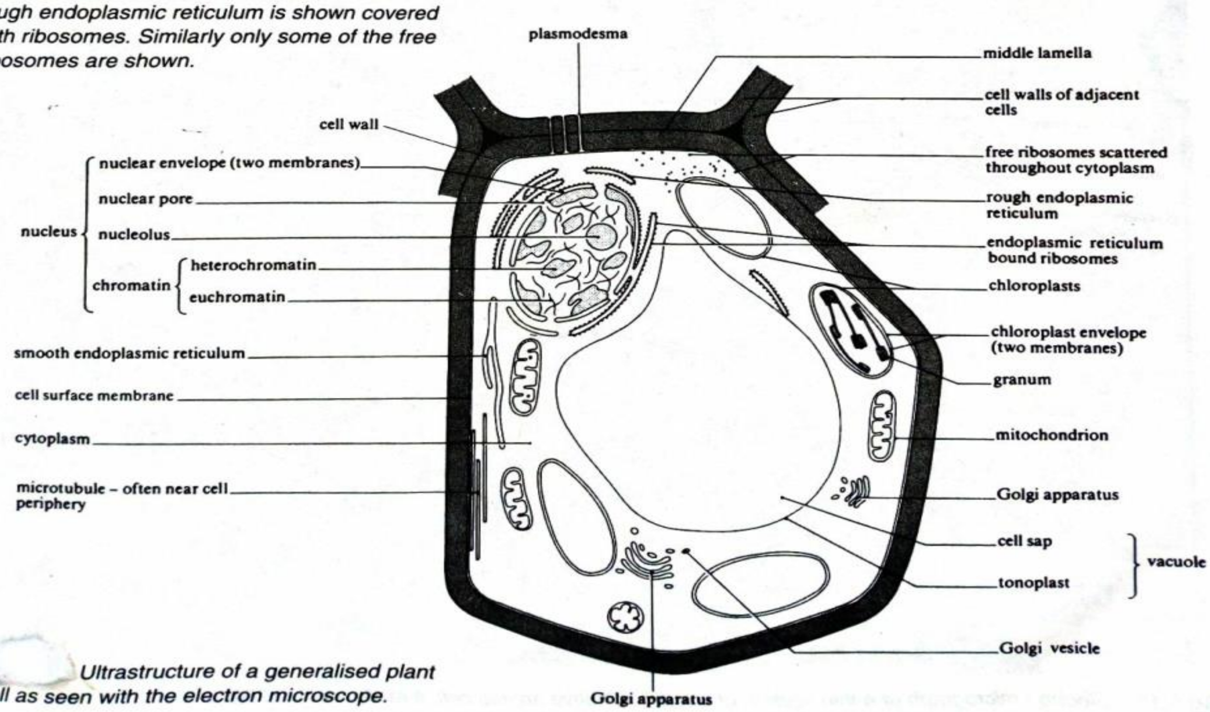
2. **PLANT CELL** This is made up.
   a) Cell membrane.

b) Cell wall
c) Plasmodesmata
d) Cytoplasm. Made up of ; i) cytosol,
   ii) Cell organelles, These include; Ribosomes, Mitochondria, Endoplasmic reticulum (smooth and Rough), Nucleus, Vacuole, Chloroplast , Microtubules.
   iii) Cytoplasmic inclusions; these include; Fat droplets, Starch grains.

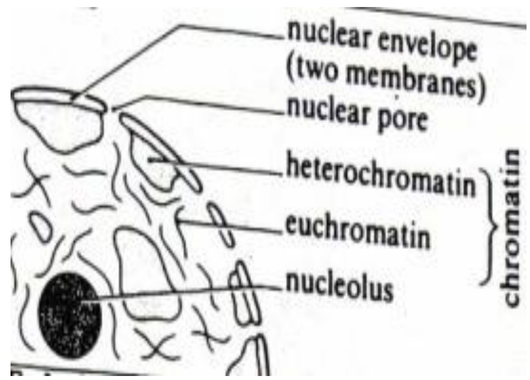
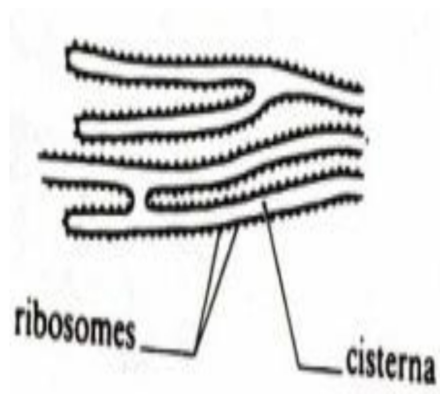
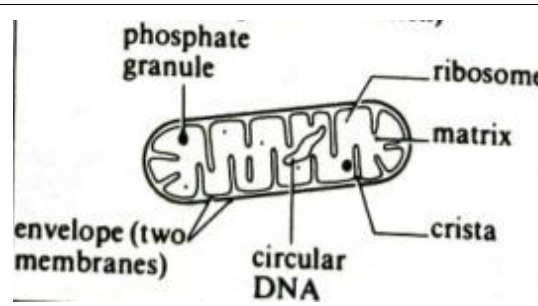
QN. Generate similarities and differences between Plant and animal cells as seen by an Electron microscope.

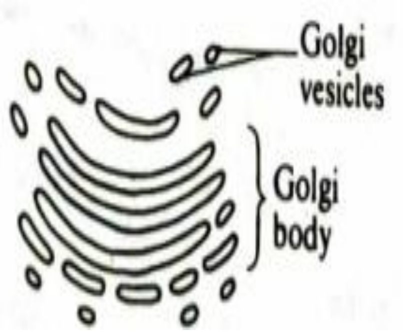
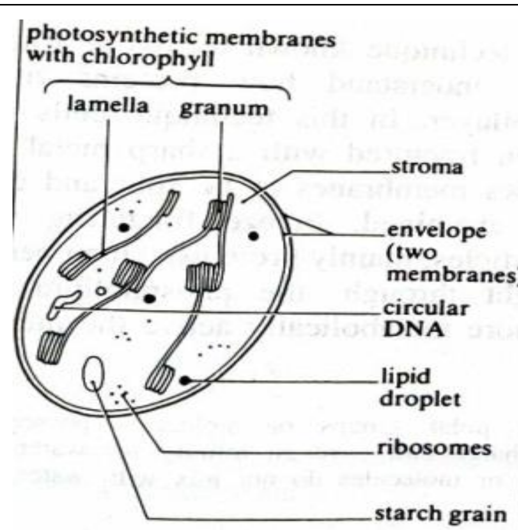


Ultrastructure of a generalised animal cell as seen with the electron microscope. NB for simplicity, only some of the rough endoplasmic reticulum is shown covered with ribosomes. Similarly only some of the free ribosomes are shown.



Ultrastructure of a generalised plant cell as seen with the electron microscope.

Structure	***Description***	***Illustration***
	Membranous Structures	
1. Nucleus	***Largest*** cell organelle, enclosed by an ***envelope*** of two membranes that is perforated by ***nuclear pores***. It contains ***Chromatin*** which is the extended form taken by chromosomes during interphase. Has ***nucleolus***. ***Functions***: **(i)** Chromosomes contain DNA the molecule of inheritance. **(ii)** DNA is organized into genes which controls all activities of the cell. **(iii)** Nuclear division is the basis of cell replication and hence reproduction. **(iv)** Nucleolus manufactures ribosomes. (v) Carry instructions for synthesis of proteins.	
2. Endoplasmic Reticulum	A system of flattened, membrane - bounded sacs called **Cisternae** (sing. Cisterna), forming tubes and sheets. It is continuous with the outer membrane of the nuclear envelope. ***Functions***: Provides a large surface area for chemical reactions. (a) ***Rough*** Endoplasmic Reticulum, RER (Has ribosomes on its surface): (i) Transports proteins made by ribosomes through Cisternae. (ii) Produces proteins especially enzymes. (b) ***Smooth*** endoplasmic Reticulum, SER (Has no ribosomes on its surface): (i) Site of lipid and steroid synthesis. (ii) Producing and storing carbohydrates. (iii) Contains lytic enzymes.	
3. Mitochondrion (plural ; mitochondria)	Surrounded by an envelope of two membranes, the inner being folded to form ***Cristae*** (sing, crista). Contains a **matrix** with few ribosomes, a circular DNA molecule and phosphate granules. ***Functions:*** In Aerobic respiration, cristae are sites of oxidative phosphorylation and electron	

	transport, and matrix is site of Krebs cycle enzymes.	
4. Golgi apparatus	A stack of flattened, membrane – bounded sacs called ***cisternae***, continuously being formed at one end of the the stack and budded off as ***vesicles*** at the other. ***Functions:*** (i) Internal ***processing*** of many cell materials at the cisternae, e.g. proteins from ER. (ii) Golgi vesicles ***transport*** materials to other parts of cell or to the cell surface for secretion. (iii) Makes lysosomes. (iv) Producing secretory enzymes e.g. the digestive enzymes of the pancreas. (v) Secreting carbohdrates such as those involved in production of new cells.	
5. Lysosomes [lysis – 'splitting', soma – 'body']	A single spherical sac bounded by a single membrane and containing digestive (hydrolytic) enzymes. ***Functions:*** Many functions all concerned with breakdown of structures or molecules for example: (i) **Autophagy**, digest parts of cell e.g. Old organelles. (ii) **Autolysis,** self-digestion of cell. (iii) Digest bacteria taken in by phagocytosis. (iv) **Exocytosis**, release their enzymes outside the cell to breakdown other cells.	
6. Chloroplast:	Large **plastid** containing chlorophyll and currying out photosynthesis. It is surrounded by an **envelope** of two membranes and contains a gel like ***stroma*** through which runs a system of membranes that are stacked in places to form **grana**, which contain flattened sacs called ***thylakoids*** (where photosynthetic pigment e.g. chlorophyll is located) It may store starch. The stroma also contains ribosomes, circular DNA molecule and lipid droplets. ***Function:*** organelle in which photosynthesis takes place.	

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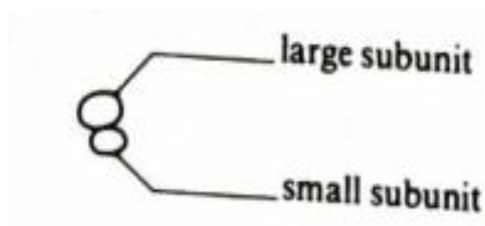
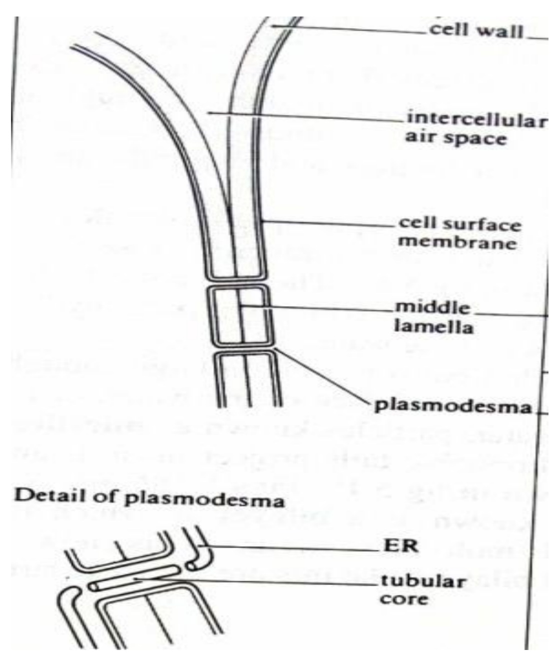
7. Large central vacuole (Small vacuoles may occur in plant and animal cells such as food vacuoles and contractile vacuole)	A fluid-filled sac bounded by a single membrane called ***Tonoplast***. Contains ***cell sap***, a concentrated solution of various substances e.g., sugars, pigments (anthocyanins), organic acids, enzymes. ***Functions***: (i) Storage of various substances including waste products, food. (ii) Makes important contribution to the osmotic properties of the cell. (iii) Sometimes functions as lysosome. (iv) **Anthocyanins**, are of various colours, may colour petals attract insect pollinators.	
8. Micro bodies Peroxisomes	A small, roughly, spherical organelle bound by a single membrane. ***Function***: All contain catalase an enzyme that breakdown hydrogen peroxide.	
Non membranous structures		
1. Ribosomes	Very small organelles consisting of large and small sub units. They are made of roughly equal parts of protein and RNA called **ribosomal RNA**. Slightly smaller ribosomes are found in mitochondria and chloroplasts in plants. ***Functions***: protein synthesis, they are either found on ER or lie free in cytoplasm. They may form ***polysomes*** (polyribosomes), a collection of ribosomes strung along messenger RNA.	
2. Cell wall, Middle lamella, Plasmodesmata (sing. Plasmodesma)	***Cell wall***: A rigid cell wall surrounding the cell, consisting of cellulose micro fibrils running through a matrix of other complex polysaccharides, maybe secondarily thickened in some cells. ***Function***: (i) Provides mechanical support and protection. (ii) Permits movement of water through and along it. (iii) In some, presence of cutin, suberin and lignin in matrix, makes cell less permeable to substances. ***Middle lamella***: Thin layer of peptic substances (calcium and magnesium pectates) ***Function***: cements neighboring cells together.	

	Plasmodesmata: A fine cytoplasmic thread linking the cytoplasm of two neibouring cells through a fine pore in the cell walls. ***Function***: Enables a continuous system of cytoplasm, the ***symplast*** to be formed between neighboring cells for continuous transport of materials between cells.	
3. **Storage granules**: These are insoluble grains within cells or organelles. For food storage. They include: (i) **Starch grains**, occur within chloplasts and cytoplasm of plant cells. (ii) **Glycogen granules**; Occur throughout cytoplasm of animal cells, store animal starch (glycogen). (iii) **Oil / lipid droplets**, found in cytoplasm of both plant and animal cells.		
4. **Microtubules**: These are slender, unbranched tubes, made of two similar proteins alpha and beta-tubulin, bind together in a helical shape to form a hollow, straight cylinder. **Functions**: (i) Provide cytoskeleton (internal skeleton) for cells, determines their shape. (ii) Aid transportation within cells by providing routes along which materials move. (iii) Form framework along which cellulose cell wall is laid down in plants. (iv) Contribute to movement since are components of cilia and flagella.		
5. **Cilia and flagella**: Cilia are usually shorter and more numerous than flagella and occur throughout the cell surface. Both have a central structure with 9 + 2 arrangement of microtubules. The structure is called the **axoneme** ("axlethread"). The nine doublets of the axoneme originate from the **basal body**. The basal body is identical in structure with a centriole and plays a central role in the growth of the axoneme. They function to: (i) Move the entire organism e.g. protozoans. (ii) Move the cell e.g. flagellum of a sperm cell. (iii) Move materials within an organism e.g. cilia lining respiratory tract.		
6. **Centrioles**: Have same basic structure as basal bodies of cilia. Are hollow cylinders with 9+0 microtubule arrangement. They arise in distinct region of the cytoplasm called centrosome. In animals, at cell division, centrioles migrate to opposite poles of the cell, synthesize the microtubules of spindle. Are absent in higher plants.		
7. **Microfilaments**: Are very thin strands, made up of protein Actin and smaller proportion of myosin. Functions for: (i) Cell movement (amoeboid, phagocytosis, pinocytosis). (ii) Muscle contraction.		
8. **Microvilli**: Tiny finger-like projections on membranes of certain cells. Eg cells of intestinal epithelium. Actin filaments within them allow contraction, along with their large surfaces, facilitates absorption.		

Cell membrane.

Cell membranes are ***important*** for: (i) Separate contents of cell from external environments. (ii) Control exchange of materials such as nutrients and waste products between the two. (iii) Enable separate compartments to be formed within cells in which specialized metabolic process occur. (iv) Receptor sites for recognizing hormones, neurotransmitters and other chemicals.

Properties of cell membranes.

(a) ***Membranes are partially permeable***: Membranes are ***not*** simply semi – permeable (allow passage of water and other small substances such as gases but not solutes) ***but*** are best described as partially permeable

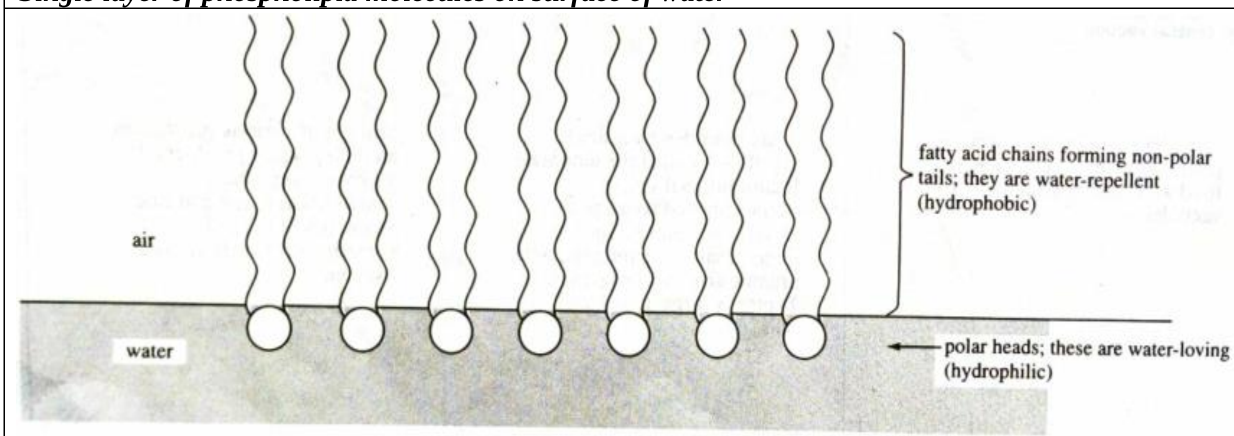
(permeable to small molecules of water and certain solutes) since other substance such as glucose, amino acids, fatty acids, glycerol and ions can diffuse slowly through them.

(b) ***Membranes contains proteins and lipids***. Organic solvents such as alcohol,, ether and chloroform, penetrate membranes more rapidly than water .This suggests that membranes have non polar portions and certain lipids. Chemical analysis showed that membranes are made up almost entirely of proteins and lipids. The most common lipids are phospholipids.

(i) ***Phospholipids.*** Each phospholipid molecule consists of a ***polar head*** containing a phosphate and two ***non-polar hydrocarbon tails*** from fatty acid used to make the molecule. ***Polar*** means there is uneven distribution of charge within the molecule, making it soluble in water. The head is ***Hydrophilic*** (water loving) and the tail is ***hydrophobic*** (water hating).

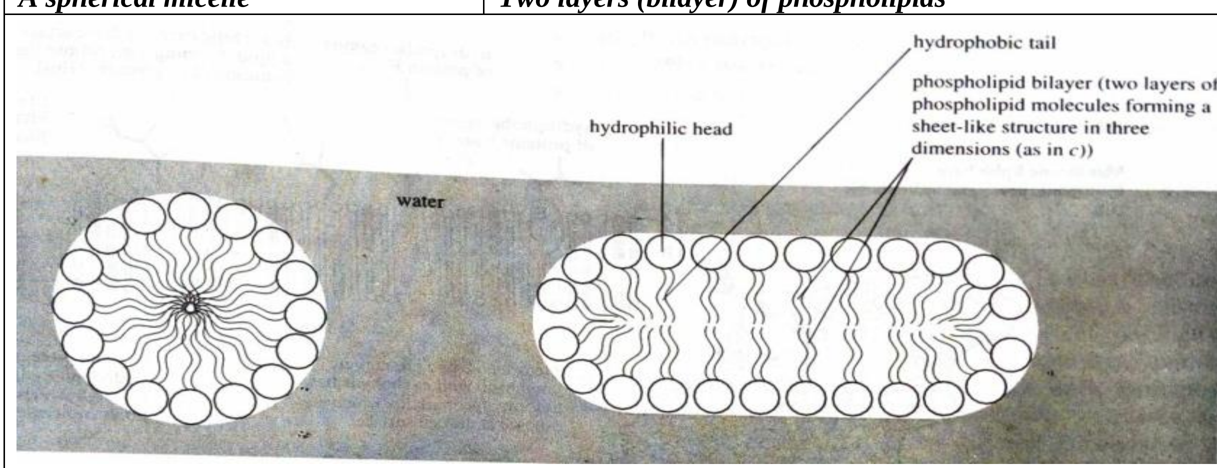
If a thin layer of phospholipid molecules is spread over the surface of water, they arrange themselves into a single layer. The non-polar hydrophobic tails project out of water, whilst the polar hydrophilic heads lie in the surface of the water.

Single layer of phospholipid molecules on surface of water



If the phospholipid is present in large enough amounts, or if is shaken up with water, particles known as ***micelles*** are formed. In which hydrophobic tails project inwards away from water. An arrangement known as a ***bilayer*** in which two layers of phospholipid molecules occur if formed. Now known that phospholipid bilayers like this are the basic structure of cell membranes.

A spherical micelle	***Two layers (bilayer) of phospholipids***



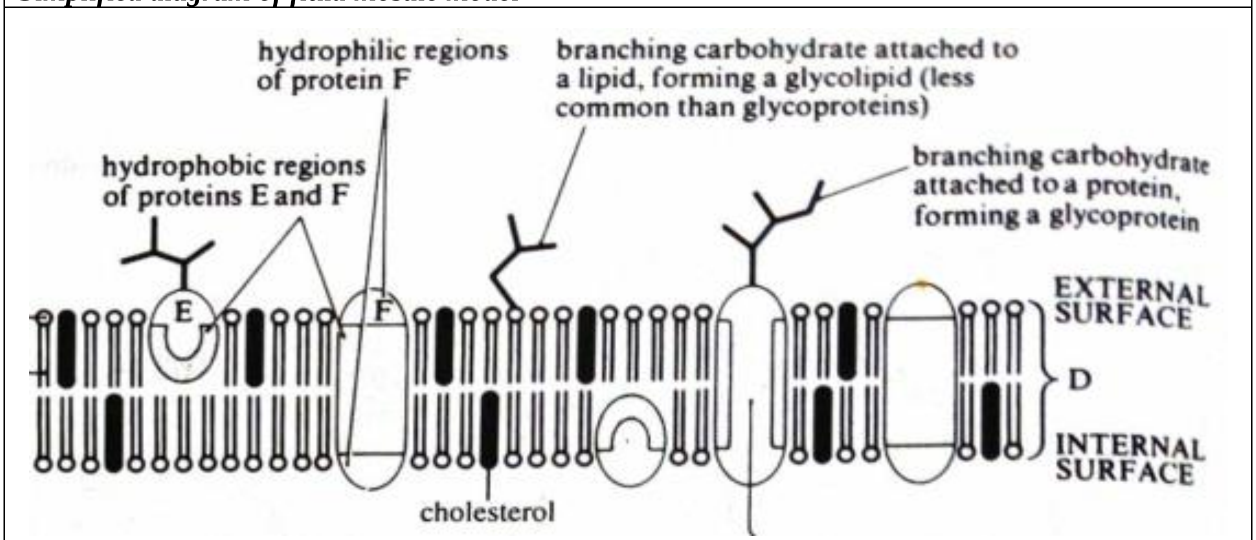
(b) ***Proteins***: A technique known as ***freeze fracturing*** is used to understand how proteins fit into the phospholipid bilayer. In this technique, cells are rapidly frozen and then fractured with a sharp metal blade. This allows membranes to be split and the surfaces inside to be examined. Freeze fracturing reveals the presence of particles, mainly proteins, which penetrate into and often right through, the phospholipid bilayer.

(c) ***Glycolipids and cholesterol:*** Glycolipid are lipids combined with carbohydrate. Like phospholipids, they have polar heads and non-polar tails. Cholesterol is closely related to lipids and slightly polar at one end.

The fluid mosaic model of membrane structure.

In 1972, Singer and Nicolson put forward the ***fluid mosaic model*** of membrane structure. According to this model, the membrane is: (i) **Fluid** because the individual phospholipid and protein molecules can move laterally, giving the membrane a flexible structure that is constantly changing in shape.(ii) **Mosaic** because the proteins that are embedded in the phospholipid bilayer vary in size, shape and pattern of arrangement.

Simplified diagram of fluid mosaic model



Description of fluid mosaic model:

(i) Phospholipid ***bilayer***, (ii) ***hydrophilic*** phosphate heads of the phospholipids face outwards into the aqueous environment inside and outside the cell. (iii) The hydrocarbon tails face inwards and create a ***hydrophobic*** interior. (iv) Phospholipids are fluids and move about rapidly by diffusion in their own layers. (v) Some of the fatty acid tails are saturated and some are unsaturated. (vi) Most protein molecules float about in the phospholipid bilayer forming a ***fluid mosaic pattern***. (vii) ***Trans membrane*** proteins stay in the membrane because they have regions of hydrophobic amino acids which interact with fatty acid tails to exclude water. The rest of the protein is hydrophilic and faces into the cell or out into the external environment both of which are aqueous. (viii) **Extrinsic** (*peripheral*) **proteins** are found at the inner and outer surfaces. Some **Intrinsic** proteins are partly embedded in any one of the phospholipid layers while others span across the two phospholipid layers. (ix) Some proteins and lipids have short branching carbohydrate chains like antennae, forming glycoproteins and glycolipids respectively. (x) In animal cells, ***Cholesterol*** molecules squeeze between the phospholipid molecules.

Functions of the membrane

The phospholipid bilayer provides basic structure of membranes. It also restricts entry and exit of polar molecules and ions. The outer molecules have a variety of functions.

(a) ***Channel proteins and carrier proteins.*** These are involved in selective transport (facilitated diffusion and active transport) of polar molecules and ions across the membrane.

(b) ***Enzymes***: Proteins sometimes act as enzymes for example microvilli on epithelial cells lining some parts of the gut contain digestive enzymes in their cell surface membranes.

(c) ***Receptor molecules***: For chemical signaling between cells, for example hormones, Neurotransmitters etc.

(d) ***Antigens***: These act as identity markers (tags), they are glycoproteins that enable cells recognize other cells and behave in an organized way for example during development of tissues and organs. Also recognition of foreign antigens by an immune system.

(e) ***Glycolipids***: Have branching carbohydrate chains and are involved in cell – cell recognition. May act as receptor sites for chemical signals.

(f) ***Energy transfer***: In photosynthesis and respiration, proteins take part in energy transfer systems that exist in the membranes of chloroplasts and mitochondria respectively.

(g) ***Cholesterol*** acts as a plug, reducing even further the escape or entry of polar molecules through the membrane.

CHECK UP

By now you should be able to: **(i)** Identify plant and animal cell structures visible under the light compound microscope. **(ii)** Draw and label detailed animal and plant cell. **(iii)** State functions of cell structures as seen under an electron microscope. **(iv)** Distinguish between plant and animal cell ultra-structures as visible under the electron microscope. **(v)** Explain the theory behind the structure of the plasma membrane. **(vi)** Describe the fluid mosaic model of plasma membranes.

Try out this

1. Which of the following accurately describes a difference between prokaryotic and eukaryotic cells? A. Prokaryotic cells have fimbriae that allow the cell to swim whereas eukaryotic cells have flagella. B. Eukaryotic cells are generally larger than prokaryotic cells. C. Eukaryotic cells have organelles. D. Prokaryotic cells have nuclei and eukaryotic cells have nucleoids.

2. What are three attributes of mitochondria and chloroplasts that suggest they were once free-living bacteria?

3. Which of the following is not true of secreted proteins? A. They are synthesized using ribosomes. B. They enter the ER lumen during translation. C. They contain a signal that directs them into the lysosome. D. They are transported between organelles in membrane-bound vesicles.

4. Which of the following results provided evidence of a nuclear localization signal in the nucleoplasm in protein? A. The protein was small and easily slipped through the nuclear pore complex. B. After cleavage of the protein, only the tail segments appeared in the nucleus. C. Removing the tail allowed the core segment to enter the nucleus. D. the SRP bound only to the tail, not the core segment.

5. Molecular zip codes direct molecules to particular destinations in the cell. How are these signals read? A. They bind to receptor proteins. B. They enter transport vesicles. C. They bind to motor proteins. D. They are glycosylated by enzymes in the Golgi apparatus.

6. How does the hydrolysis of ATP result in the movement of a motor protein along a cytoskeletal filament?

7. Compare and contrast the structure of a generalized plant cell, animal cell, and prokaryotic cell. Which features are common to all cells? Which are specific to just prokaryotes, or just plants, or just animals?

8. Cells that line your intestines are known to possess a large number of membrane proteins that transport small molecules and ions across the plasma membrane. Which of the following cell structures would you expect to be required for this function of the cells? A. the endoplasmic reticulum B. peroxisomes C. lysosomes D. the cell wall.

9. Describe how vesicles move in a directed manner between organelles of the endomembrane system. Explain why this movement requires ATP.

10. Which of the following cell structures would you expect to be most important in the growth of bacteria on the surface of your teeth? A. cell wall B. fimbriae C. flagella D. cilia.