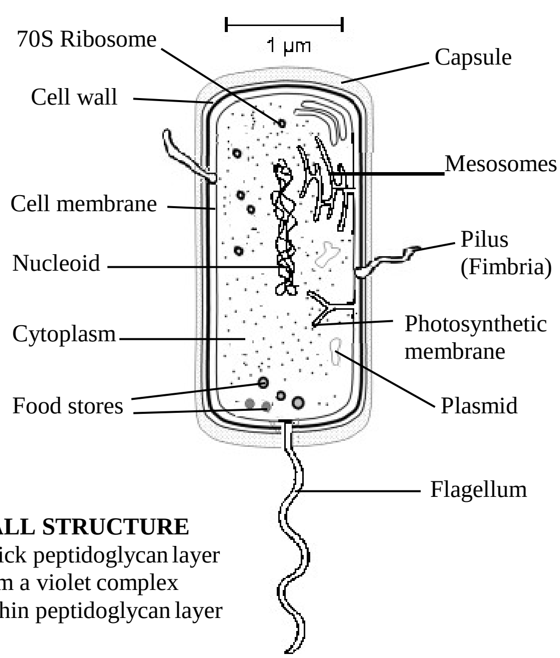
CYTOLOGY (CELL BIOLOGY): The study of structure and function of cells of plants and animals.

TERMS IN CYTOLOGY

TERM	DEFINITION	EXAMPLE / COMMENT
1. Cell	Smallest structural and functional unit of an organism capable of carrying out life processes under suitable conditions	***Life processes:*** respiration, nutrition, excretion, movement, reproduction, growth, response
2. Unicellular organism	Organism whose whole body is made of only one cell	Amoeba, paramecium
3. Multicellular organism	Organism whose body is made up of many cells	Animals and plants
4. Cytoplasm	Region within a cell composed of these **three major** elements: **cytosol**, **organelles** and **inclusions**	
(a) Cytosol	The fluid part of cytoplasm not contained within membrane-bound organelles.	
(b) Cell organelle	Separate structure within a cell which performs specific function e.g. mitochondria, chloroplast, etc	
(c) Cytoplasmic inclusion	Insoluble, non-living substance suspended in the cytosol of a cell **not** capable of carrying out any metabolic activity.	●**Glycogen granules** in liver and muscle cells. ●**Lipid droplets** in fat cells. ●**Melanin pigment** in melanocyte cells of skin and hair. ●**Water** filled **vacuoles**. ●**Crystals** e.g. (i) inside sertolli cells and leydig cells of human testes. (ii) calcium oxalate or silicon dioxide in plant cells.
5. Protoplasm	The fluid living part of the cell consisting of plasma membrane and all that it encloses.	***Protoplasm is divided into:*** (i) cytoplasm (ii) nucleoplasm (cell nucleus)
6. Prokaryotic cell	Cell without membrane-bound organelles inside.	Bacteria and cyanobacteria
7. Prokaryote	Organism without membrane-bound organelles in cells	Bacteria and cyanobacteria
8. Eukaryotic cell	Cell having the nucleus and other organelles enclosed within membranes.	Cells of plants, animals, fungi and protists
9. Eukaryote	Organism whose cells have the nucleus and other organelles enclosed within membranes.	Plants, animals, fungi and protists
10. Cytoskeleton	Complex network of fibers throughout the cytoplasm enabling maintenance of cell shape and support.	●Microfilaments ●Microtubules ●Intermediate filaments e.g. keratin.

ULTRASTRUCTURE OF PROKARYOTIC CELL
(e.g. ROD-SHAPED BACTERIUM)



Parts **ALWAYS** present

- ●***70S ribosome:*** site of protein synthesis
- ●***Cell wall:*** peptidoglycan layer that protects and maintains cell shape
- ●***Cell membrane:*** phospholipid layer controls entry and exit of substances.
- ●***Nucleoid:*** region of one free strand of DNA
- ●***Food granules:*** glycogen and lipid
- ●***Cytoplasm:*** centre for biochemical reactions.

Parts **SOMETIMES** present

- ●***Mesosome:*** site of respiration, cell wall synthesis
- ●***Flagellum:*** elongated, relatively flexible cork-screw shaped structure that moves the cell
- ●***Capsule (slime layer):*** for protection
- ●***Pili (fimbriae):*** protein filaments that facilitate cell adhesion and conjugation
- ●***Plasmid:*** independent small circle of DNA
  - Offers resistance to drugs
- ●***Photosynthetic membranes:*** where photosynthesis occurs.

DIFFERENCES IN CELL WALL STRUCTURE

(i) Gram positive cells: Have thick peptidoglycan layer that reacts with gram stain to form a violet complex

(ii) Gram negative cells: Have thin peptidoglycan layer that is not stained by gram stain.

COMPARISON OF EUKARYOTIC AND PROKARYOTIC CELLS

Feature	**Eukaryotic Cell**	**Prokaryotic Cell**
Examples	Cells of plants, animals, fungi and protists	Bacteria and cyanobacteria

Structural differences

Feature	**Eukaryotic Cell**	**Prokaryotic Cell**
Cell size	Much larger (10µm -100µm)	Much smaller (0.2µm -10µm)
Cellularity	Usually multicellular	Mostly unicellular, some cyanobacteria are multicellular
Nucleus	Present with nuclear envelope and nucleolus	Absent
DNA shape	DNA is linear	DNA is circular (has no ends))
DNA composition	DNA complexed with proteins called histones	DNA is naked, without histones
Main organelles	Present	Absent
Ribosomes	Many, larger (80S type) and 70S (in cytoplasm)	Smaller (mainly 70S type) and few **[S: Svedberg]**
Flagella	If present there's 9+2 microtubule arrangement i.e. 9 peripheral doublets surround 2 central singlets.	If present lack 9+2 microtubule arrangement
Cell wall	Chemically simpler. In plants, **cellulose** wall, fungi **chitinous** cell wall, in animals, no wall	Cell wall usually chemically complexed with **peptidoglycan**
Plasma membrane	Sterols and carbohydrates present	No carbohydrates and generally lacks sterols
Glycocalyx	Present in some cells that lack a cell wall	Present as a capsule or slime layer
Cytoplasm	Cytoskeleton present	No cytoskeleton

Functional differences

Feature	**Eukaryotic Cell**	**Prokaryotic Cell**
Cell division	Occurs by mitosis	Occurs by binary fission
Sexual reproduction	Involves meiosis	Occurs by conjugation
Cytoplasm activity	Cytoplasmic streaming occurs	No cytoplasmic streaming
Nitrogen fixation	Does not occur	Occurs in some bacteria

Similarities

Both: contain vacuoles, DNA, ribosomes, vesicles, cell wall, cytoplasm, cell membrane.

THE CELL THEORY

While Robert Hooke (1665) initially discovered cells from thinly sliced pieces of cork, it was Matthias Schleiden (1838) and Theodor Schwann (1839) who proposed the cell theory, with modifications by Rudolf Virchow (1858).

Modern ideas of the Cell Theory

1. All known living things are made up of one or more cells (Schwann and Schleiden, 1838-39).
2. The cell is the structural and functional unit of all living things (Schwann and Schleiden, 1838-39).
3. All cells arise from pre-existing cells by division (Rudolf Virchow, 1858).
4. Cells contains hereditary information which is passed from cell to cell during division.
5. All cells are basically the same in chemical composition.
6. All energy flow (metabolism and biochemistry) of life occurs within cells.

EXCEPTIONS (DISCREPANCIES) TO THE CELL THEORY

The following show properties of life but their features are not of typical / regular cells:

- Viruses are **obligate intracellular parasites** capable of replicating only inside host cells using the machinery of the host. Viruses are therefore considered **biotic** but not **organisms**.
- **Coenocytic** algae like **Vaucheria** and many **fungi** have a body that is a continuous mass of protoplasm with many nuclei but without cell wall separations i.e. are **aseptate**.
- Skeletal muscles have very long cells (up to 300 mm long) with hundreds of nuclei i.e. are **Syncytia**
- **Giant algae** is an organism made of one long cell (up to100 mm long) but with only one nucleus.
- **Unicellular organisms** can be considered **acellular** because they are larger than a typical cell/carry out all functions of life.
- Some tissues / organs contain large amounts of extracellular material *e.g.* vitreous humor of eye / mineral deposits in bone / xylem in trees.

FACTORS THAT LIMIT CELL SIZE

Factor	Explanation of how each factor influences cell size
1. Surface area to volume ratio $\frac{\text{surface area}}{\text{volume}}$	●Small cells have large SA : V ratio while large cells have a small SA : V ratio. ●A large SA : V ratio enables fast rate of diffusion while a small SA : V ratio slows the rate of diffusion. ●Small cells have low metabolic demands and form low amount of wastes while large cells have higher metabolic demands and form much amount of wastes. ●Therefore, the large SA : V ratio **in small cells** enables adequate supply of oxygen and nutrients and expulsion of wastes e.g. carbon dioxide via the surface of the cell by **simple diffusion** while the small SA : V ratio **in large cells** limits diffusion hence the **supply of nutrients** by **simple diffusion** is inadequate to meet the metabolic demands of the cell. ***Hence***: **(i)** In animals, some large sized cells take in substances in bulk by **endocytosis** and expel bulk substances by **exocytosis** to **supplement** on **simple diffusion**. **(ii)** Some animal cells increase their surface area by forming many tiny projections called **microvilli**. **(iii)** Some cells divide when they reach a certain size to maintain suitable SA : V ratio. ***Note***: ●SA : V ratio particularly **limits the size of bacterial cells**, i.e. prokaryotic cells which are incapable of endocytosis and exocytosis.
2. Nucleo-cytoplasmic ratio	●DNA in the nucleus provides instructions for protein synthesis hence controls activities of the whole cell. ●Each nucleus can only control a certain volume of cytoplasm. ●Specialization forms some long / large cells, therefore to overcome this limitation such cells are modified to become **multinucleate** / **coenocyte** e.g. skeletal muscle cells and fungal hyphae.
3. Fragility of cell membrane	●As cell size increases, the **risk of damage to the cell membrane** also increases. ●This limits the maximum size of cells, especially animal cells which lack cell walls.
4. Mechanical structures that hold the cell together	●Cells with tough cell walls e.g. plant cells are larger than cells with only the fragile cell membrane e.g. animal cells because the tough walls provide support and maintain cell shape. ●Cells with complex internal cytoskeleton are larger than cells with little cytoskeleton because the cytoskeleton protects and supports the cell structure and maintains cell shape.

ORIGIN OF EUKARYOTIC CELLS

Endosymbiotic Theory

●As proposed by **Lynn Margulis** (1967), the **endosymbiotic theory** suggests that **mitochondria** and **chloroplasts** were once separately existing small **aerobic bacteria** and **photosynthetic bacteria** respectively.

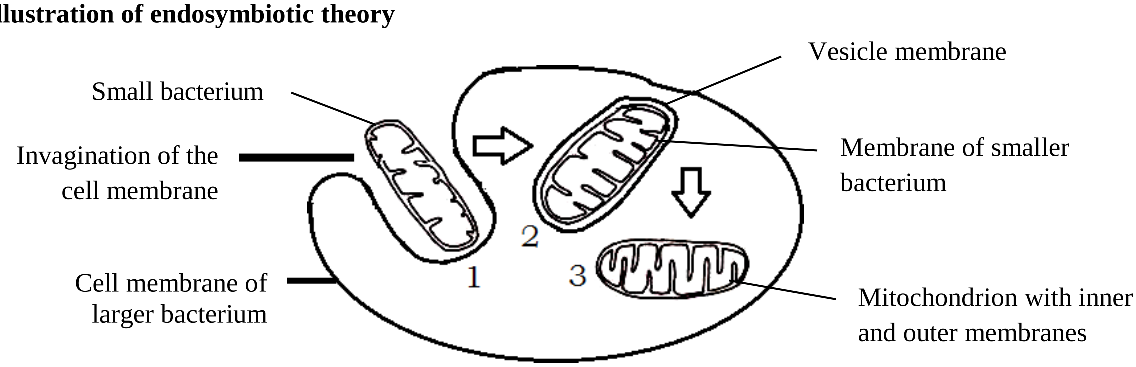
●Larger **anaerobic bacteria** engulfed the smaller bacteria by the process of **endocytosis,** but digestion failed.

●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.

●With time, mitochondria and chloroplasts were modified into **organelles** suited for respiration and photosynthesis inside the larger **eukaryotic cells.**

Note: *Secondary endosymbiosis involves a larger eukaryotic cell engulfing a smaller eukaryotic cell.*

Illustration of endosymbiotic theory



EVIDENCE FOR ENDOSYMBIOTIC THEORY

1. Mitochondria and Chloroplasts have their own DNA, and divide independently of the cell they live in.

2. There is great similarity between prokaryotic cells and the organelles of eukaryotic cells as shown below.

Feature	Prokaryotes	Eukaryotes	Mitochondria of eukaryotic cells	Chloroplasts of photosynthetic eukaryotes
DNA	One circular chromosome	Linear chromosomes	One circular chromosome	One circular chromosome
Replication	Binary fission (1 cell splits into 2)	Mitosis	Binary fission (1 splits into 2)	Binary fission (1 splits into 2)
Ribosomes	"70 S"	"80 S"	"70 S"	"70 S"
Electron Transport Chain	Occurs in the plasma membrane	In mitochondria and chloroplasts	In the membrane of mitochondrion	In the membranes of chloroplast
Approx. Size	~1 µm -10µm	~50 µm - 500 µm	~1 µm -10 µm	~1 µm -10 µm

3. The timeline of life on Earth shows that from fossil evidence of bacterial life, the mitochondria, chloroplasts and eukaryotic cells emerged at about the same time, 1.5 billion years ago.

Feature	Prokaryotes	Eukaryotes	Mitochondria of eukaryotic cells	Chloroplasts of photosynthetic eukaryotes
Appearance on Earth	***Anaerobic bacteria:*** ~3.8 Bn yrs ago ***Photosynthetic bacteria*:** ~3.2 Bn yrs ago ***Aerobic bacteria*:** ~2.5 Bn years ago	~1.5 billion yrs ago	~1.5 bn years ago	~1.5 bn years ago

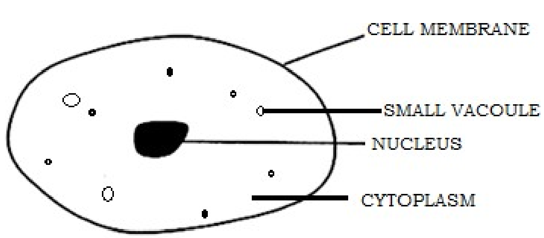
- At about 3.8 billion years ago, the atmosphere of the Earth did not contain oxygen, and all life was **anaerobic**.
- About 3.2 billion years ago, **photosynthetic bacteria** or **cyanobacteria** appeared and accumulated **oxygen** in the atmosphere from their photosynthesis, which killed **anaerobic** cells.
- **Aerobic** cells appeared at about 2.5 Billion years ago, followed by mitochondria, chloroplasts and eukaryotic cells at almost the same time, approximately 1.5 billion years ago.

SEMI-AUTONOMOUS ORGANELLES

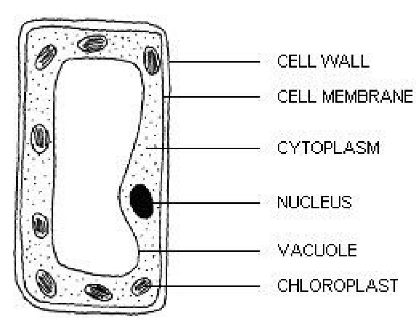
- Mitochondrial DNA and chloroplast DNA is short hence provides only a small part of the **genome** needed for **binary fission,** hence the process in organelles is controlled by the nucleus which contains the larger genome.
- Mitochondrial DNA and chloroplast DNA is short, therefore can only code for a few of the proteins needed, hence some of the required proteins are imported from the cytoplasm of the main cell where the organelle stays.

GENERALISED STRUCTURE OF CELLS AS OBSERVED UNDER LIGHT MICROSCOPE

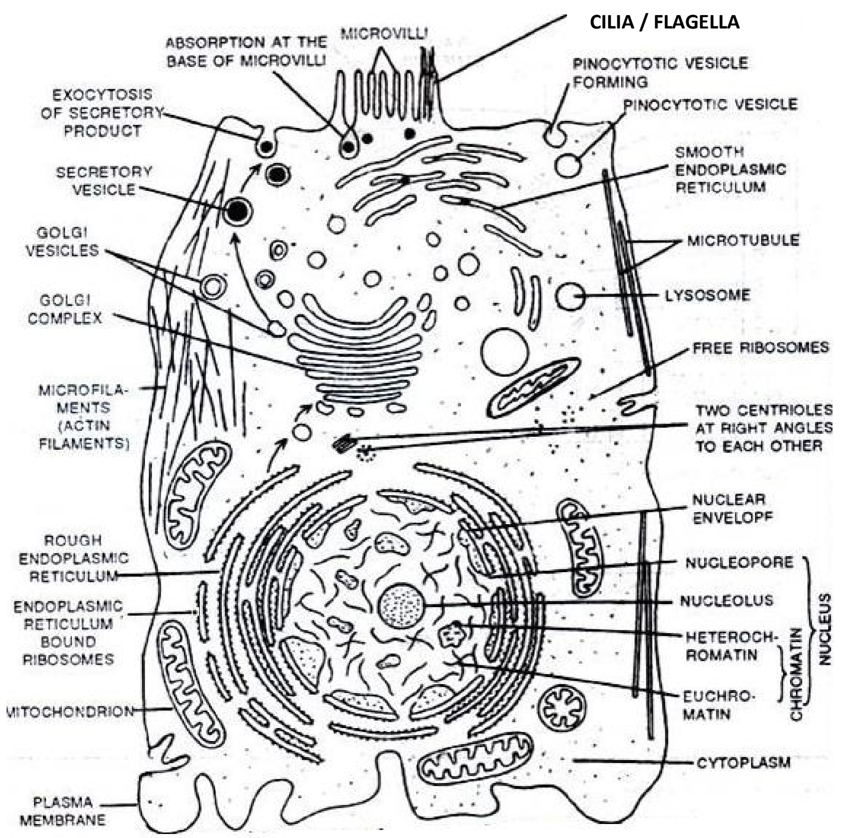
Animal cell



Plant cell



ULTRASTRUCTURE OF CELLS (AS OBSERVED BY ELECTRON MICROSCOPE)



Parts of a typical animal cell

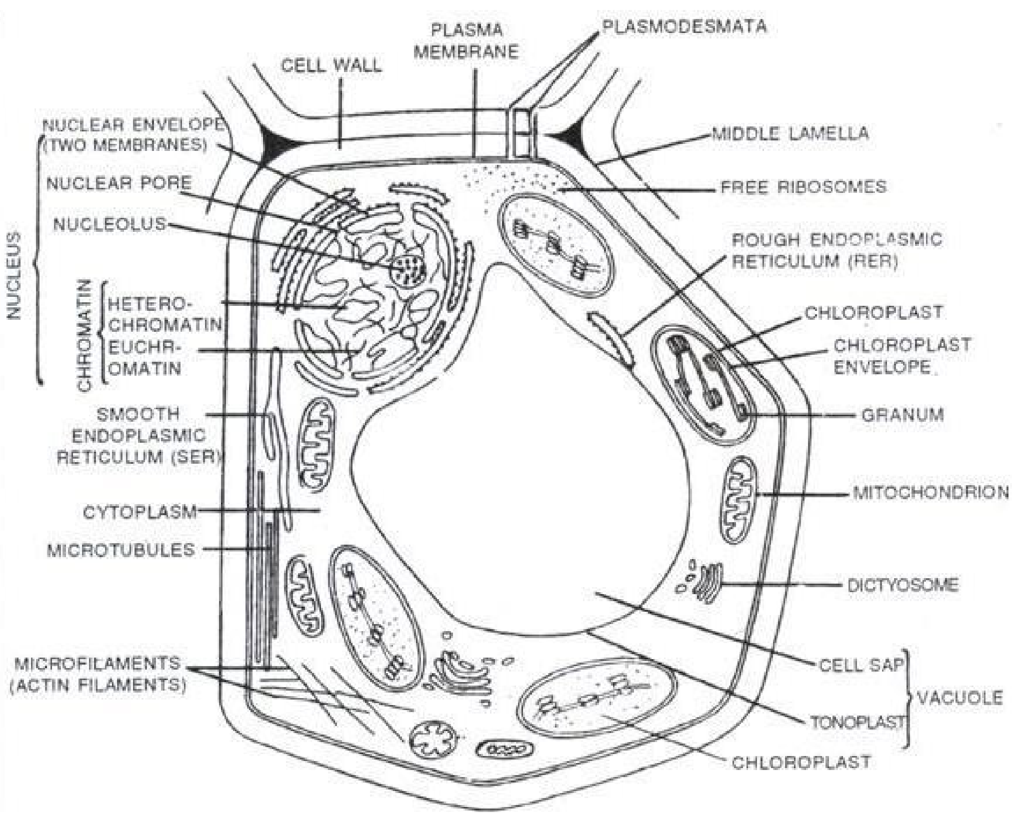
1. Cell membrane
2. Cytoplasm
(a) Cytosol
(b) Cell organelles
(c) Cytoplasmic inclusions

Cell organelles

(i) Nucleus
(ii) Ribosomes (free or attached to ER)
(iii) Endoplasmic reticulum (SER/RER)
(iv) Mitochondria
(v) Golgi complex (Golgi apparatus)
(vi) Lysosomes
(vii) Microfilaments
(viii) Centrioles
(ix) Microvilli
(x) Cilia and Flagella
(xi) Microtubules

Cytoplasmic inclusions

(i) Pinocytic vesicles
(ii) Glycogen granules
(iii) Fat droplets



Parts of plant cell

1. Cell membrane
2. Cell wall
3. Plasmodesmata
4. Cytoplasm
(a) Cytosol
(b) Cell organelles
(c) Inclusions

Cell organelles

(i) Nucleus
(ii) Ribosomes
(iii) Endoplasmic reticulum (SER/RER)
(iv) Mitochondria
(v) Dictyosomes
(vi) Microfilaments
(vii) Microtubules
(viii) Vacuole
(ix) Chloroplasts

Cytoplasmic inclusions

(i) Starch grains
(ii) Fat droplets

COMPARISON OF PLANT AND ANIMAL CELLS

Similarities

All plant and animal cells contain the Cytoplasm, Endoplasmic Reticulum (Smooth and Rough), Ribosomes, Mitochondria, Golgi apparatus, Microtubules, Microfilaments, Nucleus, lipid droplets

Differences

Feature	**Animal Cell**	**Plant Cell**
Cell wall	Absent	Present, made of cellulose
Plastids	Absent	Present e.g. ***chloroplasts***
Plasmodesmata	Absent	Present
Cilia	Present on some cells	Most plant cells lack cilia.
Centrioles	Present in cytoplasm	Absent
Cholesterol in cell membrane	Present	Absent
Centrioles	Present in all animal cells	Only present in lower plant forms.
Vesicles	Present	Absent
Shape	Irregular shapes	Fixed shapes
Vacuole	Vacuoles small, many, scattered in cytoplasm	Vacuole is 1, large (90% of cell volume), central position
Food stored	Glycogen	Starch

Note: In plants and fungi, **lysosomes** are called **acidic vacuoles**.

STRUCTURE OF THE CELL MEMBRANE

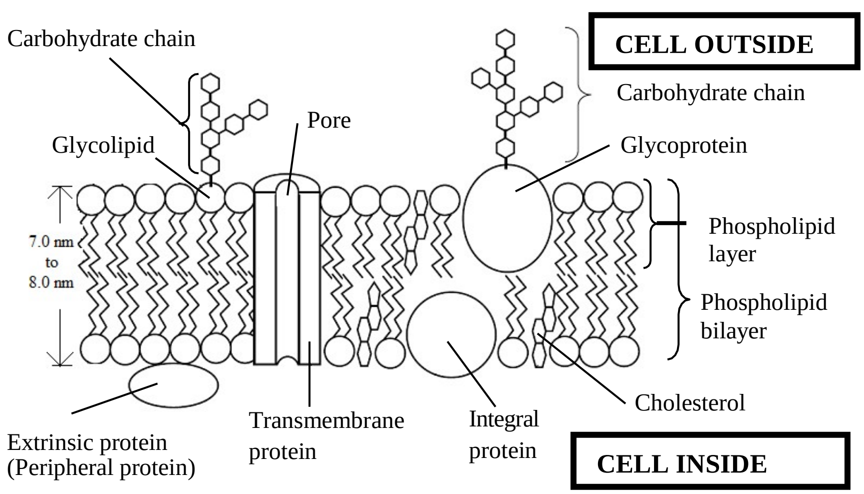
According to **S. J. Singer** and **G. L. Nicolson (1972)**, the structure of the cell membrane is a **fluid-mosaic model.**

It is described as:

- **Fluid** because the individual phospholipid and protein molecules can move laterally, giving the membrane a flexible structure that is constantly changing in shape.
- **Mosaic** because the proteins that are embedded in the phospholipid bilayer vary in size, shape and pattern of arrangement.

The main components of the cell membrane are: **1.** Phospholipids **2.** Proteins **3.** Carbohydrates **4.** Cholesterol

Fluid mosaic model of the cell membrane



Description fluid mosaic model

- Two layers of phospholipids (Phospholipid bilayer), whose lipid tails face inwards of the membrane while phosphate heads face outwards.
- Phosphate heads are **polar**, **hydrophilic** and form **hydrogen bonds** with water.
- Lipid tails are **non-polar, hydrophobic** and are attracted to each other by **hydrophobic interactions** and **Van der Waals forces**.
- **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.
- Some **transmembrane** proteins are **porous**.
- Some proteins conjugate with short, branched carbohydrates to form **glycoprotein**.
- Some phospholipids conjugate with short, branched carbohydrates to form **glycolipid**.
- In animal cells, cholesterol molecules squeeze between the phospholipid molecules.

NOTE: **The cell membrane is supported by intracellular microfilaments at the inner surface which act as cytoskeleton**

RESEARCH QUESTION: (a) Describe SIX roles of cell membrane proteins.
(b) How is the cell membrane SUITED for its functions?

OTHER TOPICAL QUESTIONS: See last page (page 20)

CELL MEMBRANE FUNCTIONS

Component	Function
1. General	Forms a protective barrier between the inside and outside of the cell and determines cell shape.
2. Proteins	●Glycoproteins work as antigens in immunity. ●Channel proteins allow diffusion of polar ions and molecules across the membrane. ●Transport proteins move ions or solutes by active transport e.g. sodium ions or by facilitate diffusion e.g. glucose, amino acids across the membrane ●Membrane proteins provide sites for cytoskeleton filaments to anchor to support and maintain cell shape. ●Membrane proteins join cells together forming tissues which perform specific functions. ●Glycoproteins are involved in cell-to-cell recognition by cells of complimentary sites e.g. specific hormones. ●Cell surface receptor proteins are involved in signal-transduction by converting an extracellular signal to an intracellular one. ●Some membrane proteins have enzymatic properties e.g. ATP synthase for ATP synthesis. ●Some membrane proteins work as electron carriers in electron transport chains
3. Glycolipids	Are involved in cell-to-cell recognition
4. Cholesterol	Stabilizes membrane structure by preventing phospholipids from closely packing together
5. Lipid bilayer	Being semi-permeable, it controls movement of substances in and out of the cell

MEMBRANE FLUIDITY

Membrane fluidity refers to the viscosity of the lipid bilayer of a cell membrane

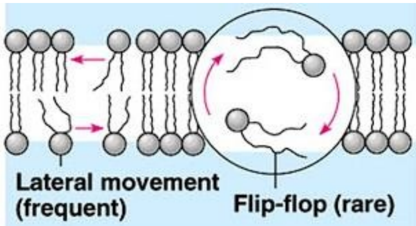
Importance of regulating membrane fluidity

●Membranes must be fluid to work properly.
●Biological processes stop when the bilayer fluidity reduces too much e.g. membrane transport and enzyme activities.

Factors that affect membrane fluidity

Factor	How the factor influences membrane fluidity
1. Temperature	●Low temperature decreases membrane fluidity because lipids are laterally ordered, the lipid chains pack well together, mobility reduces to allow many stabilising interactions. ●Increase in temperature increases membrane fluidity because lipids acquire thermal energy to become mobile and reduce stabilising interactions.
2. Length of lipid tails	●Lipids with shorter chains are more fluid because they quickly gain kinetic energy due to their smaller molecular size and have less surface area for Van der Waals interactions to stabilise with neighboring hydrophobic chains. ●Lipids with longer chains are less fluid because their large surface area enables more Van der Waals interactions hence increasing the **melting temperature**.
3. Lipid saturation	●Lipid chains with double bonds (unsaturated fatty acids) are more fluid because the kinks caused by double bonds make it harder for the lipids to pack together. ●Lipids that have single bonds only (saturated fatty acids) have straightened hydrocarbon chain which pack together to reduce membrane fluidity.
4. Presence of cholesterol e.g. in membranes of animal cells	●At low temperatures, cholesterol increases membrane fluidity by preventing fatty acid hydrocarbon chains from coming together and crystallizing there by inhibiting the transition from liquid to solid (decreases the membrane freezing point). ●At warm temperature (e.g. 37^0C) cholesterol decreases membrane fluidity by interacting with lipid tails to reduce their mobility, thereby increasing the melting point. ●At high concentrations, cholesterol also prevents fatty acid hydrocarbon chains from coming together and crystallizing. **(The ratio of cholesterol to lipids in a membrane can be as high as 1:1)**

Effect of lipid tail movement

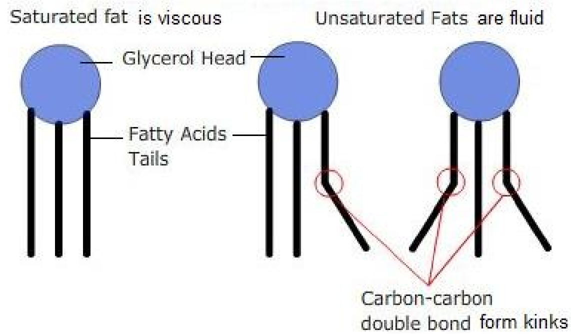


Note

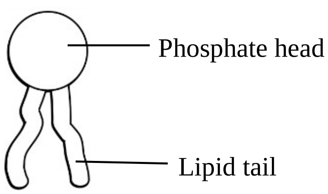
1. Most of the lipids and some proteins drift laterally

2. Rarely does a molecule flip-flop transversely across the membrane.

Effect of *fatty acid unsaturation*



Structure of phospholipid



Phospholipid

- The phosphate head is composed of glycerol and phosphate
- Tail made from two fatty acids, which could be saturated or unsaturated fatty acid

Arrangement in membrane

- Phospholipids form a bilayer, where the heads face outside the membrane / tails face inside the membrane

How phospholipid properties maintain cell membrane structure

- Phospholipids are held together by hydrophobic interactions
- Phospholipid layers are stabilized by interaction of hydrophilic heads and surrounding water
- Phospholipids allow for membrane fluidity/ flexibility
- Fluidity/ flexibility enables membranes to be functionally stable
- Phospholipids with short fatty acids and those with unsaturated fatty acids are more fluid
- Fluidity is important in breaking and remaking membranes (e.g. endocytosis / exocytosis)
- Phospholipids can move about / move laterally (horizontally) / "flip flop" (move transversely) to increase fluidity
- Hydrophilic / hydrophobic layers restrict entry/ exit of substances.

DISTRIBUTION AND FUNCTION OF MEMBRANES OF CELLS

Membranes of cells DOES NOT only include the **cell membrane (plasma membrane)**, which forms the cell boundary plus its **various modifications**, BUT ALSO all **other membranes** enclosing **some organelles** and some **cytoplasmic inclusions** within cells.

Distribution	**Function**
Plasma membrane	● Forms a protective barrier between the cell inside and outside. ● Determines cell shape and provides cell stability. ● Selectively regulates entry and exit of substances.
Nuclear envelope	● Separate nuclear contents from cytoplasm hence limits DNA within the nucleoplasm but allows exit of RNA. ● Controls flow of information to nucleus and DNA that are carried by the macromolecules.
Outer mitochondrial membrane	● Allows entry of ATP, NADH and from glycolysis
Inner mitochondrial membrane	● Contains electron carriers in electron transport chain
Rough Endoplasmic Reticulum	● Intracellular transport and sites for ribosome attachment
Smooth Endoplasmic Reticulum	● Intracellular transport
Outer chloroplast membrane	● Allows photosynthetic products out and substrates in
Thylakoid membranes of chloroplasts	● Store photosynthetic pigments e.g. chlorophyll ● Contains electron carriers
Golgi complex membrane	● Storage of glycoprotein ● Synthesis of polysaccharides e.g. cellulose in plants
Lysosomes	● Isolates autolytic enzymes from unnecessary digestion of cell components
Tonoplast	● Limits cell sap within the vacuole
Membranes surrounding vesicles	● Limit the contents of the vesicles within until when ready for exit e.g. calcium ions and neurotransmitters in neurones, undigested materials in phagocytic vesicles, etc.
Neurilemma of neurones	● Contains protein pumps for Na+ and K+ which bring about impulse propagation
Myeline sheath membrane	● Insulates nerve fibre to increase transmission speed.

STRUCTURE OF PLANT CELL WALL

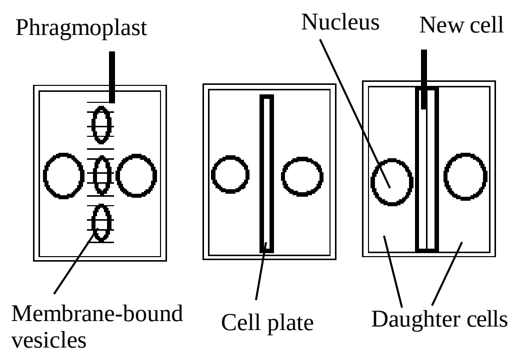
NOTE*:** Plant cell wall is an **extracellular component** of plant cells. ***Others: glycoprotein and basement membrane.

- The cell wall consists of **3** main layers (regions) i.e. **middle lamella; primary cell wall;** and **secondary cell wall**
- It is tough**;** usually flexible/bendable/fairly rigid**;** of variable thickness [1 µm - 10µm] **;** surrounding plant cells**;**
- The outermost layer (middle lamella) cements (binds/glues) adjacent plant cells together**;** and is rich in **calcium** and **magnesium pectates** and **proteins;**
- The next layer (primary cell wall)**;** is generally a thin**;** flexible and extensible**;**
- It consists mainly of **cellulose microfibrils; hemicelluloses; pectin; water; and protein;** In plant epidermis it is usually **impregnated** with **cutin** and **wax;** to form an impermeable barrier called **plant cuticle;**
- The various chemical components are tightly (closely) bound together**;**
- In **some cells** there is the secondary cell wall inside the primary cell wall**;** It is **thick/** has **3 layers;** and contains several **proteins;** and **polymers** like: **cellulose**, **hemicelluloses** and **lignin** in ***WOOD*** and ***XYLEM*;** **suberin** in ***CORK*** and ***ROOT CASPARIAN STRIPS*; silica crystals** in ***GRASS*;**
- Certain small areas of the cell wall remain unthickened to form **pits;** which concide in adjacent cells to form pit pairs in which the two cells are separated only by the middle lamella and through which **plasmodesmata** (**cytoplasmic strands**) pass**;**

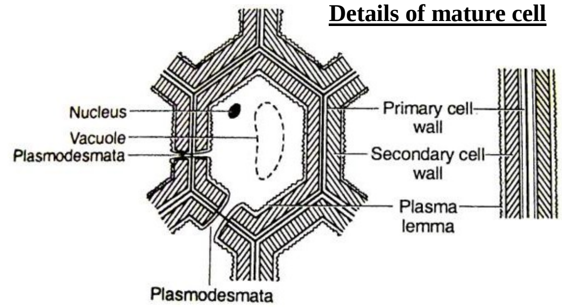
FORMATION OF PLANT CELL WALLS

- Cell wall forms during telophase stage of cell division when the **cell plate** forms between daughter cell nuclei.
- Cell plate forms from a series of vesicles produced by **Golgi** (**Dictyosomes)**.
- Vesicles migrate along the microtubules and actin filaments within the **phragmoplast** and move to the cell equator.
- **Phragmoplast** contains mitotic spindles, microtubules, microfilaments, and endoplasmic reticulum surrounded by nuclear envelopes.
- Vesicles join up their contents, and the membranes of the vesicle become the new cell membrane.
- Dictyosomes synthesize the non-cellulosic polysaccharides like **pectins** and transported to build the middle lamella.
- **Cellulose** is made at the cell surface, catalyzed by the enzyme cellulose synthase.
- While the cell plate is growing, segments of smooth endoplasmic reticulum are trapped within it, later forming the **plasmodesmata** connecting the two daughter cells

Stages of Cytokinesis in a plant cell



Details of mature cell



Functions of plant cell wall

- Maintaining / determining **cell shape.**
- **Provides support** and **mechanical strength** to the cell against gravity.
- Pathway for water and dissolved mineral salt movement by the **apoplast** pathway.
- Prevents excessive entry of water to the cell in a hypotonic medium (*i.e.,* resists turgor pressure of the cell)
- Has a **metabolic role** *i.e.,* some of the proteins in the wall are enzymes for transport and secretion.
- In **suberized cells**, acts as **physical barrier** to: (a) pathogens; and (b) water loss.
- **Carbohydrate storage** - components of the wall can be reused in other metabolic processes, like in seeds.
- allows turgor pressure/high pressure to develop inside the cell;

QUESTION

Eukaryotic cells have intracellular and extracellular components. State the functions of one named extracellular component. *(Any one of: cell wall/Glycocalyx/basement membrane/bone matrix, etc.)*

How the plant cell wall is suited for functioning

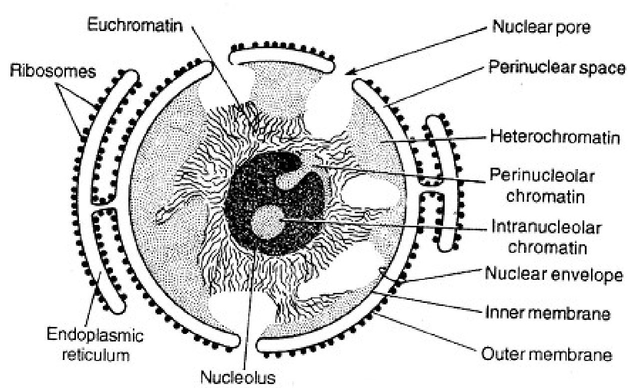
STRUCTURE	FUNCTION
• Cellulose polymers associate through very many H-bonds whose cumulative bonding energy provides high tensile strength of the cell wall;	**for providing support and preventing rupturing**
• The relatively thick multiple wall layers	**provide mechanical support**
• Secondary walls may be cutinized / suberinised	**for preventing water loss**
• The variety of functional proteins like oxidative enzymes (peroxidases), hydrolytic enzymes (pectinases, cellulases)	**enable performing several functions like protection against pathogens, cell expansion, cell wall maturation**
• The extreme rigidity of secondary wall	**provides compression strength**
• Deposition of cellulose fibrils in alternating layers	**enables some degree of flexibility**
• semi-permeable nature	**Allows exchange of water, dissolved salts and small protein molecules**

COMPARISON OF PLANT CELL WALL AND PLASMA MEMBRANE
Differences

CELL WALL	PLASMA MEMBRANE
• Number of main layers / regions varies (2 or 3) • Skeleton mainly made of carbohydrates / polysaccharides • More permeable to molecules • Lacks transmembrane proteins • Plasmodesmata present • May be lignified and suberinised • Has middle lamella • Secondary thickening occurs	• Number of main layers / regions constant • Skeleton mainly made of phospholipids • Less permeable to molecules • Transmembrane proteins present • Plasmodesmata absent • Lacks lignification and suberinisation • Lacks middle lamella • Lacks secondary thickening

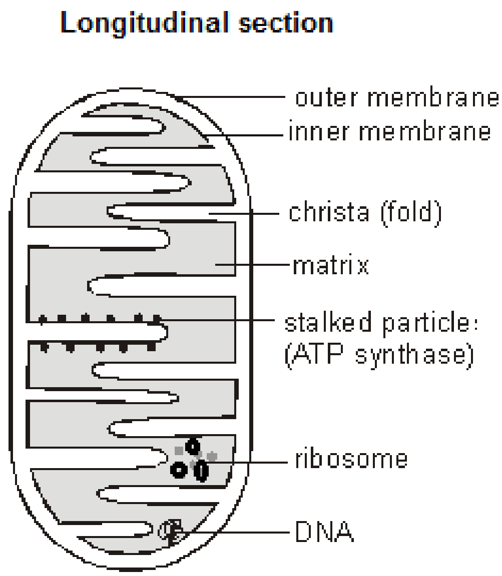
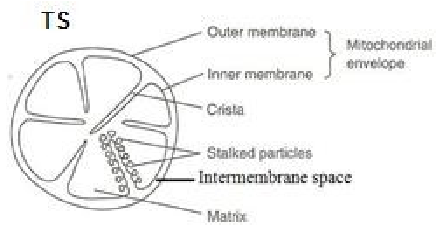
TASK: Outline the similarities between cell wall and cell membrane

NUCLEUS

Description of nuclear structure	Drawing of the nucleus	Adaptations of nucleus
●Cell nucleus is enclosed / bound by a double-layered nuclear membrane (nuclear envelope); ●Outer membrane is connected to the endoplasmic reticulum; ●A fluid-filled space (perinuclear space) exists between the two layers of a nuclear membrane. ●Nuclear membrane is perforated by nuclear pores ~50 nm in diameter ●Enclosed within the inner membrane are the nucleoplasm (karyoplasm), nucleolus and chromosomes (chromatin); ●Nucleolus is a dense, spherical-shaped structure; ●Chromosomes (chromatin) are thread-like. (i) **Heterochromatin:** stain darkly, genetically inactive, tightly coiled. (ii) **Euchromatin:** loosely packed, genetically active and enriched	 **Functions of the nucleus** **(i)** Controls the heredity features of an organism. **(ii)** Controls protein synthesis, cell division, growth and differentiation. **(iii)** Stores DNA, the heredity material **(iv)** Stores proteins and RNA in the nucleolus. **(v)** Site for transcription in which messenger RNA are produced for protein synthesis. **(vi)** Nucleolus produces ribosomes, which are the protein factories	●DNA is long to store many genes ●Nuclear membrane has pores; for exchange of DNA and RNA between the nucleus and cytoplasm; ●Presence of nucleolus; enables production of ribosomes which are protein factories; ●Nuclear envelope; isolate nucleus from interference by processes in cytoplasm; ●Nuclear pores are narrow; regulate entry and exit of substances

MITOCHONDRION

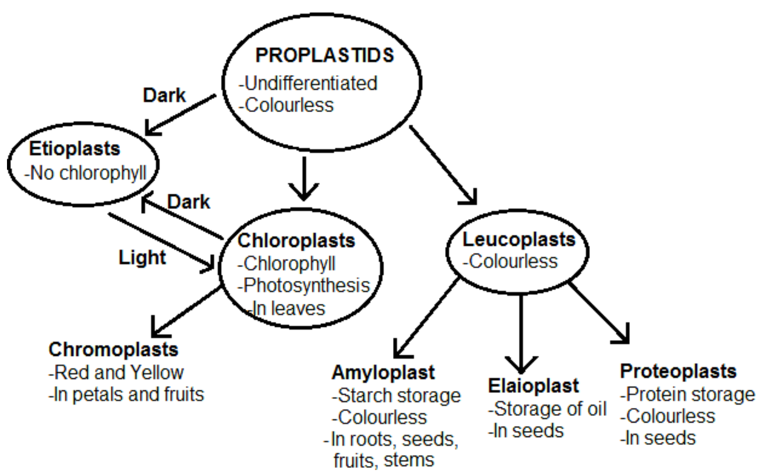
***Function*:** It is the site for aerobic respiration for production of ATP that powers cell activities.

Description of structure	Drawings of mitochondrion from LS and TS	Adaptations of mitochondrion
●Mitochondrion has a diameter of about 0.5 µm – 1µm, length of 2.0µm - 7µm; and variable shape (may be spherical /rod shaped / filamentous); ●It is double (2) membrane bound; outer membrane is entire; inner membrane folds into the mitochondrial matrix to form cristae; and in-between the two membranes is the intermembrane space. ●Mitochondrial matrix is fluid filled, with several enzymes, small sized ribosomes and circular DNA ●Each membrane is a phospholipid bilayer, with variable phospholipid compositions and protein-to-lipid (PTL) ratios. **The PTL ratio for the outer membrane is about 50:50 while that of the inner membrane is about 80:20**		●Double membranes isolate the mitochondrion from interference by processes in the cytoplasm ●Small size gives large surface are to volume ratio for rapid uptake / release of materials ●Matrix contains enzymes of Krebs cycle. ●Inner membrane forms cristae to increase the surface area for electron transport chain ●Inner membrane contains stalked particles that make ATP ●Narrow intermembrane space enables H^+ ion concentration gradient to be rapidly established for chemiosmosis to occur ●Inner membrane contains molecules for electron transport pathway ●DNA is present to act as genetic material for synthesis of some protein ●Many ribosomes for protein synthesis to reduce on importing proteins from cytoplasm.

PLASTIDS FAMILY OF ORGANELLES

These are small organelles in the cytoplasm of plant cells, containing pigments or food

Examples of plastids



Proplastid: Undifferentiated organelle which develops into **plastid**.

1. Etioplasts – colourless in absence of light, turn into chloroplasts on exposure to light

2. Chloroplasts (*chloros* - green) manufacture carbohydrates by photosynthesis.

Chloroplasts form chromoplasts

Chromoplasts (*chromos* - color) contain xanthophyll or carotenes, hence the yellowing in fruits, vegetables, and leaves.

3. Leucoplasts are colourless and include:

(a) Amyloplasts: form and store starch in tubers of roots and stem.

(b) Elaioplasts: Form and store oil.

(c) Proteoplasts (*Proteinoplasts***)**: Store crystalline proteins in plant seeds.

CHLOROPLASTS

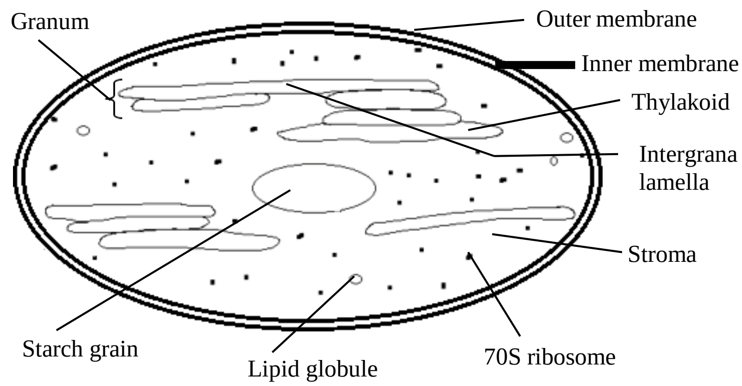
***Main function*:** It is the site for manufacture of food by the process of **photosynthesis**.

Other functions:

(i) Ribosomes enable amino acid and protein synthesis.
(ii) They produce fatty acids
(iii) They store starch, but only temporarily
(iv) Produce new chloroplasts and pigments

CHLOROPLAST STRUCTURE

- Chloroplast shape and size vary from biconvex in higher plants with length of ~5 µm to filamentous in algae, spherical, ovoid, etc.
- It is enclosed by an envelope of double membranes; outer membrane is semi-permeable.
- Inner membrane surrounds the stroma, regulates entry and exit of materials to the chloroplast, and is a manufacturing centre for fatty acids, lipids and carotenoids.
- Intermembrane space is narrow, ~10 nm-20 nm in between the outer and inner membranes.
- Stroma is semi-gel-like fluid, alkaline, rich in protein (e.g. enzymes), with chloroplast DNA, 70S ribosomes, starch granules, lipid globules and thylakoid membrane system.
- Thylakoids are interconnected, membranous sacs, with chlorophyll in the membranes.
- At intervals, thylakoids form piles (~10-20) known as **grana**.



Adaptations of chloroplast for its functions

- Outer membrane is semi- permeable to regulate entry and exit of substances for maintaining internal chloroplast environment.
- Abundant light trapping pigments for photosynthesis
- Abundant enzymes catalyse photosynthetic reactions in the stroma.
- Extensive network of thylakoid membranes increase surface area for photosynthesis.
- Narrow intermembrane space enables H^+ ion concentration gradient to be rapidly established for chemiosmosis to occur
- Inner membrane contains molecules for electron transport pathway
- DNA is present to act as genetic material for synthesis of some protein
- Many ribosomes for protein synthesis to reduce on importing proteins from cytoplasm.

COMPARISON OF CHLOROPLAST AND MITOCHONDRION

Similarities:

Both: are enclosed by double membrane, contain DNA, contain 70S ribosomes, have electron transport chain, produce ATP by chemiosmosis, contain ATP synthase /ATPase

Chloroplast	Mitochondrion
● Site of photosynthesis	● Site of respiration
● Contains thylakoid membranes	● Lacks thylakoid membranes.
● Contains photosynthetic pigments that absorb light	● Lacks photosynthetic pigments.
● There is light generated ATP production	● ATP production by oxidation of organic molecules
● H+ gradient across thylakoid membrane	● H+ gradient across inner membrane
● Cristae absent	● Cristae present
● Larger size	● Smaller size

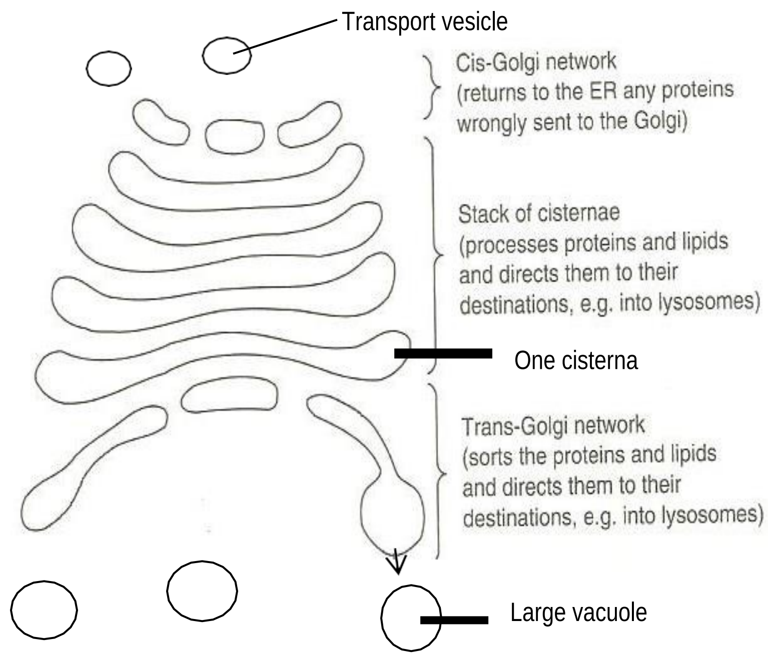
GOLGI COMPLEX (PLANTS: DICTYOSOME)

Note:

1. Golgi is abundant in **secretory** cells and in rapidly **dividing** cells e.g. pancreatic cells, goblet cells, salivary glands, cells in testes and ovaries.
2. Golgi complex is the cell's **"post office"** or **"shipping department"** where molecules are packaged, labelled and sent to different parts of the cell.

STRUCTURE OF GOLGI COMPLEX

- Golgi complex is made up of piles (stacks) of flattened sacs called **cisternae** (*singular*: **cisterna**) with vesicles budding (pinching) off at edges of sacs;
- One cisterna is a flattened sac, with a lumen enclosed by a single membrane.
- Between 4-8 cisternae pile up to form a stack which bends to form a semi-circle.
- A cell may have 40 to 100 stacks.
- An individual stack of the cisternae is sometimes referred as **dictyosome**.
- The Golgi complex contains a number of separate compartments, as well as some that are interconnected.
- The cisternae stack has 4 functional regions: the cis-Golgi network, medial-Golgi, endo-Golgi, and trans-Golgi network.
- The cisternae carry structural proteins important for their maintenance as flattened membranes which stack upon each other.



The *cis* face is adjacent to the endoplasmic reticulum and the **trans** points towards the plasma membrane.

FUNCTIONS OF GOLGI APPARATUS	ADAPTATIONS OF GOLGI
●To modify, sort and package proteins that are made at the rough endoplasmic reticulum for secretion (export) or for use within the cell. ●To form carbohydrates e.g. polysaccharides are attached to a protein to form **proteoglycans** present in the extracellular matrix of the animal cell. ●Transport of lipid molecules around the cell. ●Formation of lysosomes containing hydrolytic enzymes. ●Formation of peroxisomes. ●In plant cells, Golgi produces vesicles that join to form cell plates during cell division. ●Secretory vesicles produced by Golgi contain a variety of important substances e.g. neurotransmitters, hormones, mucin, zymogen e.g. pepsinogen, etc. ●Fusion of Golgi vesicles with cell membrane maintains the membrane which is used to form phagocytic vacuoles and Pinocytic vesicles ***Note***: Golgi complex is the cell's **"post office"** or **"shipping department"** where molecules are packaged, labelled and sent to different parts of the cell.	●Cisternae are enclosed by selectively permeable membranes, which isolate the inside cavity from cytosol for efficient functioning. ●Tubular structure enables transportation of soluble **protein** and **lipids** from the endoplasmic reticulum for modification. ●Variety of enzyme systems for modifying proteins by adding carbohydrates and phosphate by the process of **glycosylation** and **phosphorylation** respectively. ●Many cisternae increase the surface area for modifying synthesised macromolecules. ●There are many compartments at the cis, located at the beginning of the Golgi apparatus to facilitate passage of proteins through the Golgi apparatus

FUNCTIONING OF GOLGI APPARATUS

- Proteins made at Rough Endoplasmic Reticulum (RER) have, as part of their amino acid sequence, a signal that directs them where to go, just like an address directs a letter to its destination.

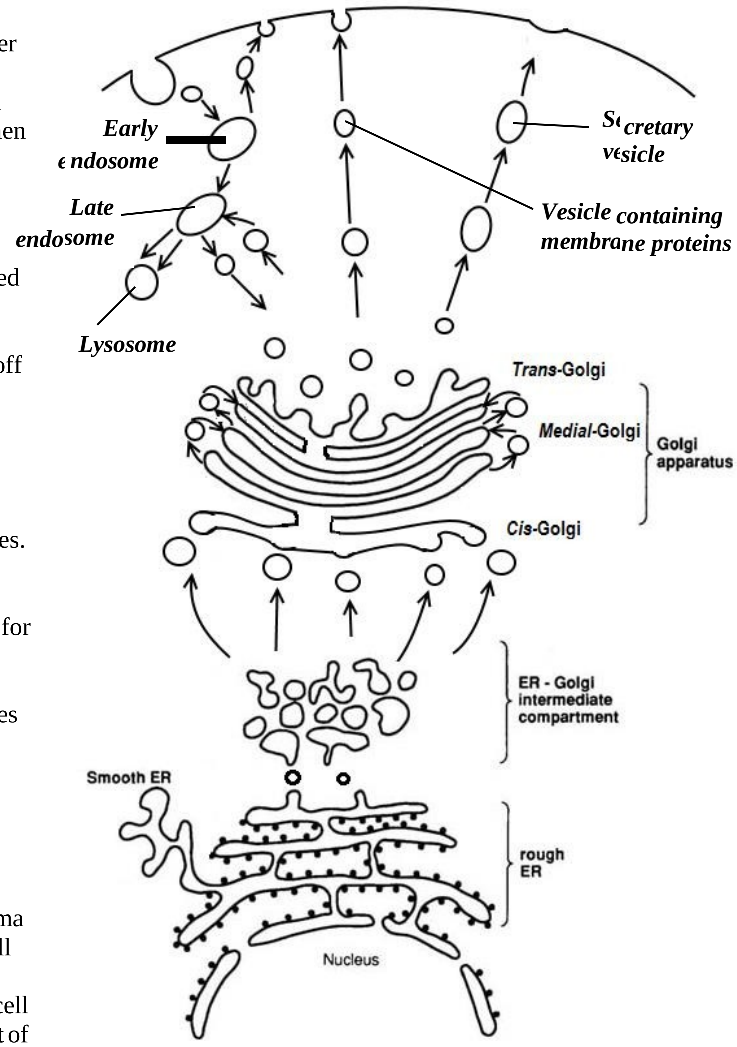
(i) Proteins arriving at *cis*-Golgi but having RER retention signal (were wrongly sent), are repackaged into vesicles then returned to RER.

(ii) Soluble or properly folded macromolecules (proteins, lipids and polysaccharides) from RER enter *cis*-Golgi network via transport vesicles

- Within *cis*-cisternae, macromolecules are partly modified i.e. carbohydrates are added to proteins (**glycosylation**), phosphate is added to protein (**phosphorylation**) etc.
- After partial modification, coated vesicles bud (pinch) off the swollen ends of *cis*-cisternae and fuse with ends of *medial* cisternae.
- Within *medial*-cisternae, different enzymes further transform macromolecules differently, depending on their structures and destination i.e. some are modified for secretion, others for the membrane, and some for lysosomes.
- After further modification within the *medial*-cisternae, coated vesicles bud (pinch) off the swollen ends of the *medial*-cisternae and fuse with the ends of *trans*-cisternae for further transformation.
- From *trans*-cisternae, the transformed macromolecules exit the Golgi and are sorted into different transport vesicles destined for **lysosomes**, **plasma membrane** or **storage vesicles** for **secretion**.

(a) Vesicles containing **hydrolase enzymes** fuse with membranes of growing **lysosomes** so that the contents of both structures fuse.
(b) Vesicles containing hormones e.g. insulin remain until when signaled by the cell, the vesicles then fuse with plasma membrane to release (**secrete**) the hormone outside the cell by **exocytosis**.
(c) Vesicles containing membrane proteins fuse with the cell membrane and some of the modified proteins become part of the cell membrane e.g. protein receptors.

THE SECRETORY PATHWAY



ENDOPLASMIC RETICULUM

This is a membrane-bound organelle which forms a network of tubules, vesicles and cisternae within eukaryotic cells, except mammalian red blood cells.

TYPES OF ENDOPLASMIC RETICULUM

- Rough Endoplasmic Reticulum (RER), studded membrane-bound ribosomes.
- Smooth Endoplasmic Reticulum (SER), without ribosomes attached.

RER is more prominent in cells concerned with protein synthesis e.g. liver cells.
SER is prominent in cells concerned with the production of lipids

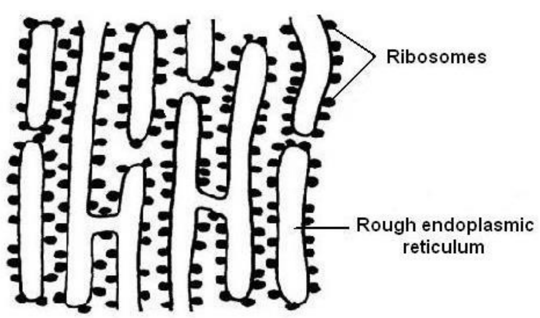
NOTE:
1. The rough and smooth endoplasmic reticulum can transform from one type to another, depending on especially the enzymatic needs of the cell.
2. The transformation happens through the embedding of proteins.

FUNCTIONS OF ENDOPLASMIC RETICULUM

Specific functions by RER	General functions by SER and RER	Specific functions by SER
●Production and processing of specific proteins at ribosomal sites, that are later exported ●Folds proteins into three dimensional shapes e.g. haemoglobin for further processing e.g. carbohydrates may be added. ●Transports ready proteins to the sites where they are required. ●Checks the quality of proteins formed, especially correct ordering and structure.	●Transporting proteins and carbohydrates to other organelles like lysosomes, Golgi apparatus, and plasma membrane. ●Form part of the cell's skeletal framework. ●Offer increased surface area for cellular reactions. ●Form the nuclear membrane during cell division.	●Synthesis of lipids and other steroids like cholesterol, progesterone and testosterone. ●Synthesis and repair of membranes by producing cholesterol and phospholipids, ●For metabolism of glycogen in the liver e.g. glucose-6-phosphatase enzyme in SER converts glucose-6-phosphate to glucose. ●Contains enzymes that detoxicate lipid-soluble drugs, alcohol and metabolic wastes from the liver. ●SER attaches receptors to cell membrane proteins in plant cells ●Sarcoplasmic reticulum regulates muscle contraction through storage and release of calcium ions.

STRUCTURE OF ENDOPLASMIC RETICULUM

Rough Endoplasmic Reticulum (RER)	Smooth Endoplasmic Reticulum (SER)
●RER is an extensive membrane network of **cisternae** (sac-like structures), which are held together by the cytoskeleton. ●A phospholipid membrane encloses a space, the lumen from the cytosol, which is continuous with perinuclear space. ●The surface of the rough endoplasmic reticulum is studded with ribosomes, which give it a rough appearance hence the name **rough endoplasmic reticulum**. ●A part of RER is continuous with the nuclear envelope	●The SER is a folded structure composed of a network of interconnected disc-like sacs and tubules called **cisternae** which are held in their place by the cytoskeleton. ●The SER is bound by a phospholipid membrane enclosing a fluid-filled space known as **cisternal space** or **lumen**. ●The lumen or cisternal space is continuous with the perinuclear space. ●A part of SER is continuous with the nuclear envelope, some other part may be at the periphery of the cell.



ADAPTATIONS OF ENDOPLASMIC RETICULUM

●The interconnected network provides the cell with skeletal framework.
●Forming an extensive network increases the surface area for metabolic reactions e.g. protein synthesis at RER.
●*The endoplasmic reticulum membrane compartmentalizes the cytoplasm (isolates lumen from cytosol), which:*
(i) Enables transporting soluble and well packaged substances to their **specific** destinations.
(ii) Prevents interference of different metabolic processes taking place in the cell at the same time.
●Contains a variety of enzymes for performing diver roles in cell metabolism.
●The SER is modified into sarcoplasmic reticulum storage and release of calcium ions.
●The membrane has a variety of proteins that offer unique properties including signal reception.
●The RER membrane has sites for attachment of many ribosomes for protein synthesis

LYSOSOMES

- These are tiny spherical sac-like structures surrounded by a single membrane containing **powerful** hydrolytic **enzymes**.
- They are mostly abundant in secretory cells e.g. epithelial cells, in phagocytic cells e.g. liver cells and kidney cells.
- Lysosomes are also referred to as **"suicide bags", "digestive bags", "cell garbage disposal system"**, etc.

STRUCTURE OF LYSOSOMES

- Irregular / spherical, sac-like structure enclosed by a single membrane, about 1 μm in diameter.
- A single lysosome contains over **50 different enzymes** known collectively as **acid hydrolases,** in an acidic medium (about pH 4.8 to 5).
- Lysosomal membrane has a protein complex that is highly **glycosylated** forming a continuous **glycoprotein layer**, whose structure consists of a **mucin-like** domain that resists break down by enzymes within the lysosome.

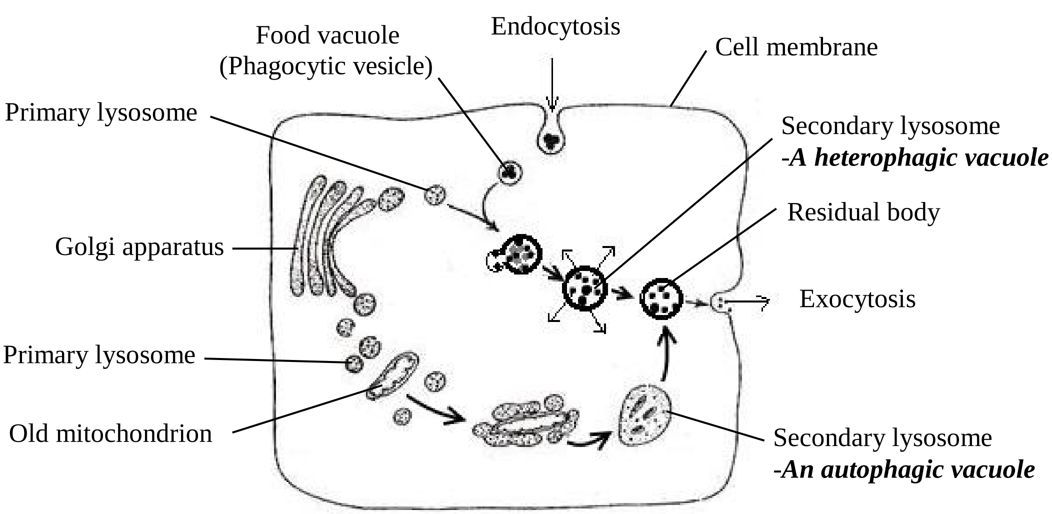
MAIN TYPES OF LYSOSOMES

- ***Primary lysosome:*** This is the lysosome produced at the Golgi complex, containing many hydrolytic enzymes.
- ***Secondary lysosome:*** This is the lysosome formed by the combination of a primary lysosome with a food vacuole, in which **lysis** takes place through the activity of **hydrolytic enzymes**.

FUNCTIONS OF LYSOSOMES

Function	**Explanatory notes**
1. Autophagy	**Primary lysosome** fuses with worn-out cellular components like mitochondrion to form **autophagic vacuole** in which digestion occurs by lysosomal enzymes into end products which leave by **diffusion** or with the aid of **specialized transporters** into cytoplasm while undigested materials (**residual body**) is released outside by **exocytosis**.
2. Heterophagy (Cellular digestion)	**Primary lysosome** fuses with food vacuole engulfed by **endocytosis** to form **digestive vacuole (heterophagic vacuole)** in which digestion occurs by lysosomal enzymes into end products which leave by **diffusion** or with the aid of **specialized transporters** into cytoplasm while undigested materials (**residual body**) is released outside by **exocytosis**.
3. Autolysis	Primary lysosome releases hydrolytic enzymes within a dead cell to digest the **whole** cell.
4. Development processes	● Tadpole metamorphosis (regression of tail) and regression of Wolffian ducts involve shedding of tissues with removal of whole cells and extracellular material by lysosome enzymes ● During bone development, osteoclasts release lysosomal enzymes that remodel bones.
5. Role in fertilization	● Acrosome in spermatozoa releases enzymes which digest the limiting membrane of the ovum to enable sperm entry and start fertilization. ● The lysosome in cytoplasm of Ova enables digestion of stored food.
6. Role in immunity	Leucocytes (WBC) digest foreign particles, bacteria and viruses enabled by lysosomes.
7. GERL system	Golgi, Endoplasmic Reticulum and Lysosome system regulates the secretory activities of the Golgi and ER as well as modification of secretory products.

ILLUSTRATION OF AUTOPHAGY AND HETEROPHAGY IN THE ANIMAL CELL



NOTE:
Endocytosis forms **endosomes** (membranes surrounding food particles) of various sizes:

1. **Pinocytosis** forms **vesicles** (less than 100nm in diameter)

2. **Phagocytosis** forms **vacuoles** (more than 100nm in diameter)

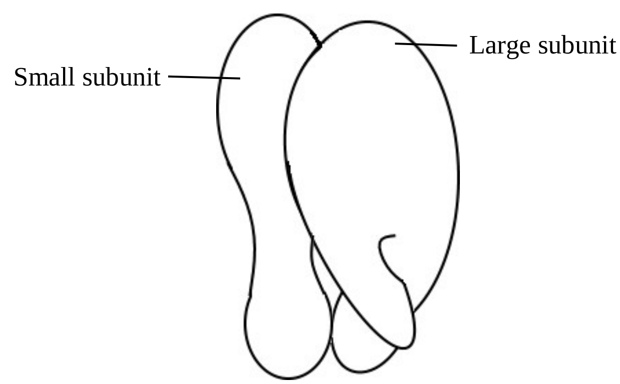
RIBOSOMES
These are small (diameter of 20 nm -30nm), non-membranous particles made up of a large and small subunits, present in large numbers in all living cells.
Function: Site of protein synthesis.

- Ribosomes are made of large (protein) and small (rRNA) subunits.
- Ribosomes on rough endoplasmic reticulum form proteins for export out of the cell e.g. hormones, etc.
- Ribosomes that occur freely in the cytoplasm make proteins that remain with cytoplasm e.g. dissolve in solution or form structural cytoplasmic elements.
- Prokaryotes have 70S ribosomes (small subunit of 30S and large subunit of 50S) while Eukaryotes have mainly 80S ribosomes which are larger and more complex, each consisting of small (40S) and large (60S) subunit.

S stands for the Svedberg unit for sedimentation velocity

- The ribosomes share a core structure which is similar to all ribosomes despite differences in its size

STRUCTURE OF ONE RIBOSOME



MICROBODIES
Examples:
(i) **Peroxisomes**, which contain a variety of enzymes that rid the cell of toxic wastes e.g. catalase breaks down hydrogen peroxide, liver microbodies detoxify alcohol and fat-soluble drugs.
- Peroxisomes and lysosomes are similar in appearance, but differ in origin. Lysosomes are formed in the Golgi complex, whiles peroxisomes self-replicate using protein imported from the cytosol.

(ii) **Glyoxysomes**, which contain enzymes that degrade lipids into sugars during seed germination.

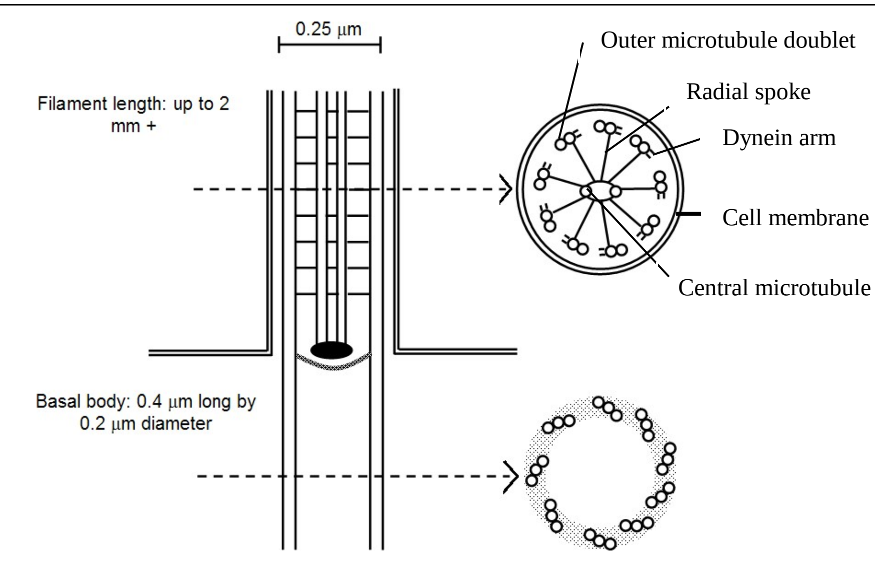
CILIA AND FLAGELLA
Cilia and flagella are structurally identical structures.

Cilia	**Flagella**
Numerous	Less in number
Short and hair-like organelle (about 10µm)	Long whip-like organelle (about 150µm)
Occur throughout the cell surface	Presence at one end
Beat in coordination	Beat independently
Show sweeping movement or pendular stroke	Undulatory movement

STRUCTURE OF CILIA AND FLAGELLA

- Both the cilia and flagella arise from a small granular structure called **basal body.**
- Cilia and flagella are covered by a unit membrane, which is an extension of the cell membrane.
- There is a central filament called **axoneme** formed of 11 microtubules arranged in the pattern of 9+2 i.e. 2 central singlets (single microtubules) and 9 peripheral doublets (pairs of microtubules).

Note:
Each centriole is made of nine triplets of microtubules arranged in a ring (9+0 pattern)



FUNCTIONS OF CILIA AND FLAGELLA
(i) Ciliary movement enables paramecium to drive food into their gullet.
(ii) In certain molluscs Ciliary movement facilitates gaseous exchange by passing water currents over the gills
(iii) In echinoderms Ciliary movement enables locomotion by driving water through the water vascular system.
(iv) Cilia lining the respiratory tract of humans drives away the microbes and dust particles towards the nose or mouth.
(v) Cilia in the oviduct or fallopian tubes of human female moves ova towards the uterus.
(vi) Cilia in nephridia of annelids e.g. earthworms moves wastes
(vii) Flagellum of sperms enables their swimming movement.
(viii) Flagellum enables the movement in certain protozoans like euglena

CYTOSKELETAL ELEMENTS
Cytoskeleton is the network formed by **microtubules, microfilaments** and **intermediate filaments**.
The **cytoskeleton** connects to every organelle and every part of the **cell membrane**, giving structural support and maintaining shape.

1. MICROFILAMENTS (ACTIN FILAMENTS)	**2. MICROTUBULES**
Structure: ●Two strands of **actin**, (a globular protein) twist around each other to form a **solid**, right-handed, long helical-shaped rod, about 5nm-9nm in diameter (***see figure next page***) ***Functions:*** ●They enable a dividing cell membrane to pinch off into two cells ●Are also involved in cell movement e.g. amoeboid movement, phagocytosis, pinocytosis, etc. ●Associate with **myosin** to cause muscle contraction. ●Support the cell membrane and maintain cell shape. ***Location:*** They nucleate at the plasma membrane, with the cell periphery (edges) having the highest concentration.	***Structure:*** ●Two alternating strands of ***alpha*-tubulin** and ***beta*-tubulin** (globular protein) bind together in a helical shape to form a **hollow**, straight cylinder with length of 200nm-25μm and diameter of about 25nm. (***see figure next page***) ***Functions:*** ●Serve as conveyor belts moving other organelles throughout the cytoplasm. ●Are the major components of cilia and flagella in cell motility ●They form spindle fibers during cell division. ●Give shape and mechanical support to the cell. ●Enable vesicles to move during cell wall formation in plants. ***Location:*** Found throughout the cytoplasm of all eukaryotic cells, forming part of **cytoskeleton** that gives structure and shape to cells.

3. INTERMEDIATE FILAMENTS
These are a broad class of fibrous proteins whose diameter ranges between 8nm-2nm.

Examples of intermediate filaments	**Functions of intermediate filaments**
(i) **Keratins** in animal epithelial cells (ii) **Desmin**, which integrates sarcolemma, Z-disc and nuclear membrane in sarcomeres of muscle cells. (iii) **Peripherin and neurofilaments** in neurons (iv) **Nuclear lamins** inside the nucleus, which attach the chromosomes to nuclear membrane and provide anchorage points for nuclear pores.	●They are tension-bearing elements that maintain cell shape and rigidity. ●They anchor in place several organelles, including the nucleus and desmosomes. ●They are involved in formation of the **nuclear lamina**, a net-like meshwork array that lines the inner nuclear membrane and governs the shape of the nucleus.

CENTRIOLES

Location: Are found only in animal cells, near the nucleus in the **centrosome** which serves as an organizing centre for microtubules. ***Structure:*** Two cylinders, held at right angle to each other, each about 0.3μm-0.5μm long and 0.24μm in diameter, made of nine triplets of microtubules arranged in a ring in a **9+0 pattern**.	***Functions:*** ●In animal cell division, centrioles organise microtubules to form spindle fibers which separate chromosomes. ●Cellular organization - centrosomes are involved in organizing microtubules, whose position determines position of organelles e.g. nucleus ●Ciliogenesis- In ciliated and flagellated organisms, the mother centriole which becomes the basal body determines the position of these organelles.

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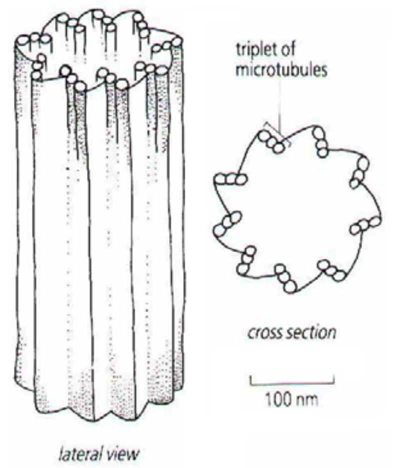
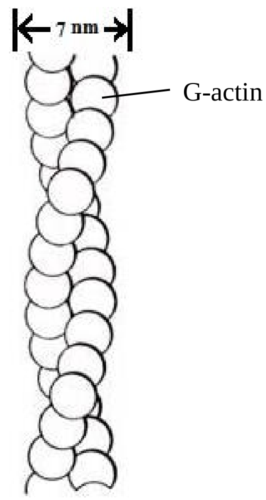
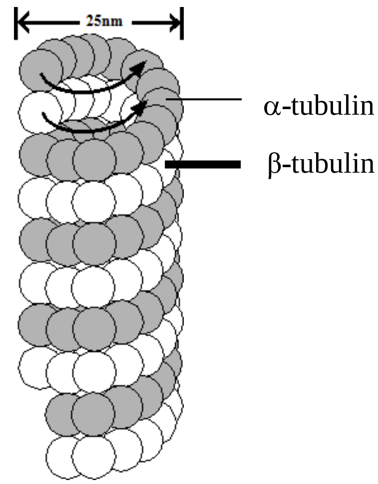
<tr><th>CENTRIOLE STRUCTURE</th><th>MICROFILAMENT</th><th>MICROTUBULE STRUCTURE</th></tr>
<tr><td>
</td><td>
</td><td>
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VACUOLES

●Plant vacuoles are large, sac-like structures in which a single membrane called **tonoplast** encloses a fluid called **cell sap**, containing water and various dissolved substances. ●In animal cells, vacuoles, when present are smaller in size.

Formation of plant vacuole

●A newly formed plant cell lacks sap vacuole. ●As the cell matures, vesicles that pinch off Golgi apparatus and RER enlarge into small vacuoles. ●Smaller vacuoles fuse together to form a large vacuole.

Functions of vacuoles

(i) The tonoplast isolates the vacuolar sap from the cytosol, enabling vacuolar pathway of water.
(ii) Vacuoles in some flowers have coloured pigments that give petals bright coloured for attracting pollinators.
(iii) Serve as stores of reserve food, secretory products or waste product.
(iv) It stores salts, nutrients, minerals, pigments, proteins etc.
(v) It maintains cell turgor by osmotic uptake of water since vacuolar sap has a higher solute concentration than cytosol.
(vi) In meristematic cells, vacuoles bring about growth by initiating cell elongation.
(vii) Serve as stores of waste products like tannins, which are excreted when leaves fall.
(viii) In fresh water protozoans like amoeba and paramecium, contractile vacuoles regulate the water content of cells.
(ix) Food vacuoles formed by phagocytosis (endosomes) enable bulk intake of food.

TOPICAL QUESTIONS FOR PAPER 2 (P530/2)

Qn. 1. (a) Distinguish between **cell organelle** and **cytoplasmic inclusion** (3 marks)
(b) Describe the fine structure of the following:
(i) Golgi complex (ii) Nucleus (iii) Mitochondrion (12 marks)
(c) How are the structures in (b) above suited for functioning? (5 marks)

Qn. 2. (a) Describe the **structure** of any two named **cytoskeletal elements**. (10 marks)
(b) State the **roles** of each of the named cytoskeletal elements in (a) above to cells. (10 marks)

Qn. 3. (a) What are the main ideas of the **cell theory**?
(b) Discuss possible exceptions to the **cell theory.**
(c) Explain how **surface area to volume ratio** and **nucleo-cytoplasmic ratio** influence cell size.

Qn. 4. (a) Describe the functioning of Golgi apparatus in animal cells.
(b) Explain the role of lysosomes in animal cells.

Qn. 5. By stating differences in structure and function, distinguish between
(a) Rough endoplasmic reticulum and Golgi apparatus
(b) Cell wall and cell membrane
(c) Cilia and flagella

Qn. 6. Give an account of
(a) Fluid mosaic model of cell membrane structure (6 Marks)
(b) The different functions of the membranes of cells. How do these functions relate to the structure of the membrane? (14 marks)

Qn. 7. (a) Describe the structure of plant cell wall (10 Marks)
(b) Compare the structures of plant cell wall and plasma membrane (07 Marks)
(c) How is the plant cell wall suited for functioning? (3 Marks)

Qn. 8. (a) Describe the structure and function of TWO eukaryotic membrane-bound organelles other than the nucleus.
(b) Prokaryotic and eukaryotic cells have some non-membrane bound components in common. Describe the function of TWO of the following and discuss how each differs in prokaryotes and eukaryotes:
(i) DNA (ii) Cell wall (iii) Ribosomes.
(c) Explain the **endosymbiotic theory** of the origin of eukaryotic cells, and discuss one example of evidence.

Qn. 9. Membranes are essential components of all cells.
(a) Identify THREE macromolecules that are components of the plasma membrane in a eukaryotic cell and discuss the structure and function of each.
(b) Explain how membranes participate in each of the following biological processes
(i) Muscle contraction (ii) Fertilization of the egg (iii) Chemiosmosis production of ATP

Qn. 10. Describe the structural arrangement and function of the membranes associated with each of the following eukaryotic organelles:
(a) Mitochondrion (b) Endoplasmic reticulum
(c) Chloroplast (d) Golgi apparatus

Qn. 11. (a) Describe the structure of a **generalized eukaryotic** plant cell.
(b) Indicate structurally how a **non-photosynthetic prokaryotic cell** differs from a generalized eukaryotic plant cell.

Qn. 12. Membrane are important structural features of cells.
(a) Describe how membrane structure is related to the transport of materials across a membrane.
(b) Describe the role of membranes in the synthesis of ATP in either cellular respiration or photosynthesis.

Qn. 13. (a) Compare the structure of chloroplast and mitochondrion in relation to function.
(b) Eukaryotic cells have intracellular and extracellular components. State the functions of one named extracellular component.