Cell structure, organelles and functions

Unit-2 - Cell structure and function

Contents:

1) What is a cell, overview of cell theory
2) Cell diversity: cell size, cell shapes and internal organization
3) Prokaryotic and Eukaryotic cells- differences
4) Animal and plant cells structural view
5) **Descriptions of basic organelle structure and functions of a typical animal cell**.----- plasma membrane, cytoplasm, nucleus, endoplasmic reticulum, ribosomes, golgi apparatus, mitochondria, lysosomes, peroxisomes, cytoskeleton, centrosomes and centrioles, vacuoles
6) Plastids –chloroplasts in plant cells

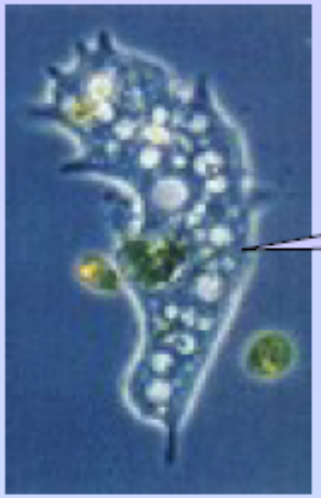
What is a cell?

- Building blocks of life
- Simplest units of life
- Chemical reactions in the cell keeps us alive

❖ **All living things are cells or composed of cells.**

- A cell is the basic structural and functional unit of all living things
  - **Eukaryotic** & Prokaryotic
  - **Animal** & Plant
- How cells fit into the rest of the body's organization

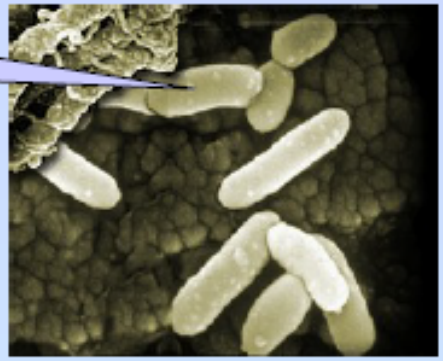
Examples of Cells



Amoeba Proteus

Plant Stem

Bacteria

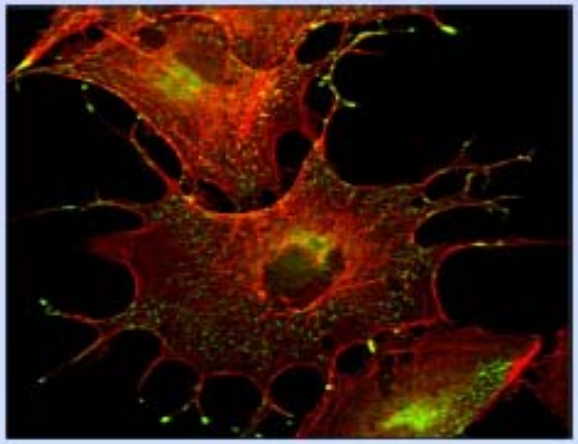


Nerve Cell

Red Blood Cell

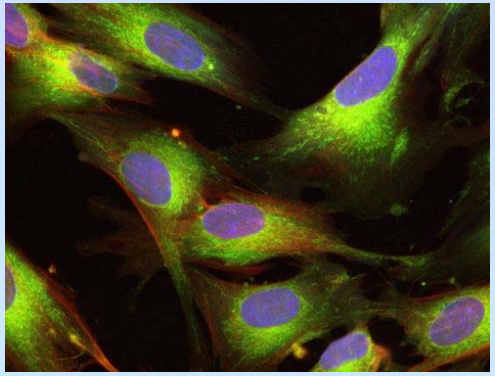
Specialised Cells

Red Blood Cell



Nerve Cell

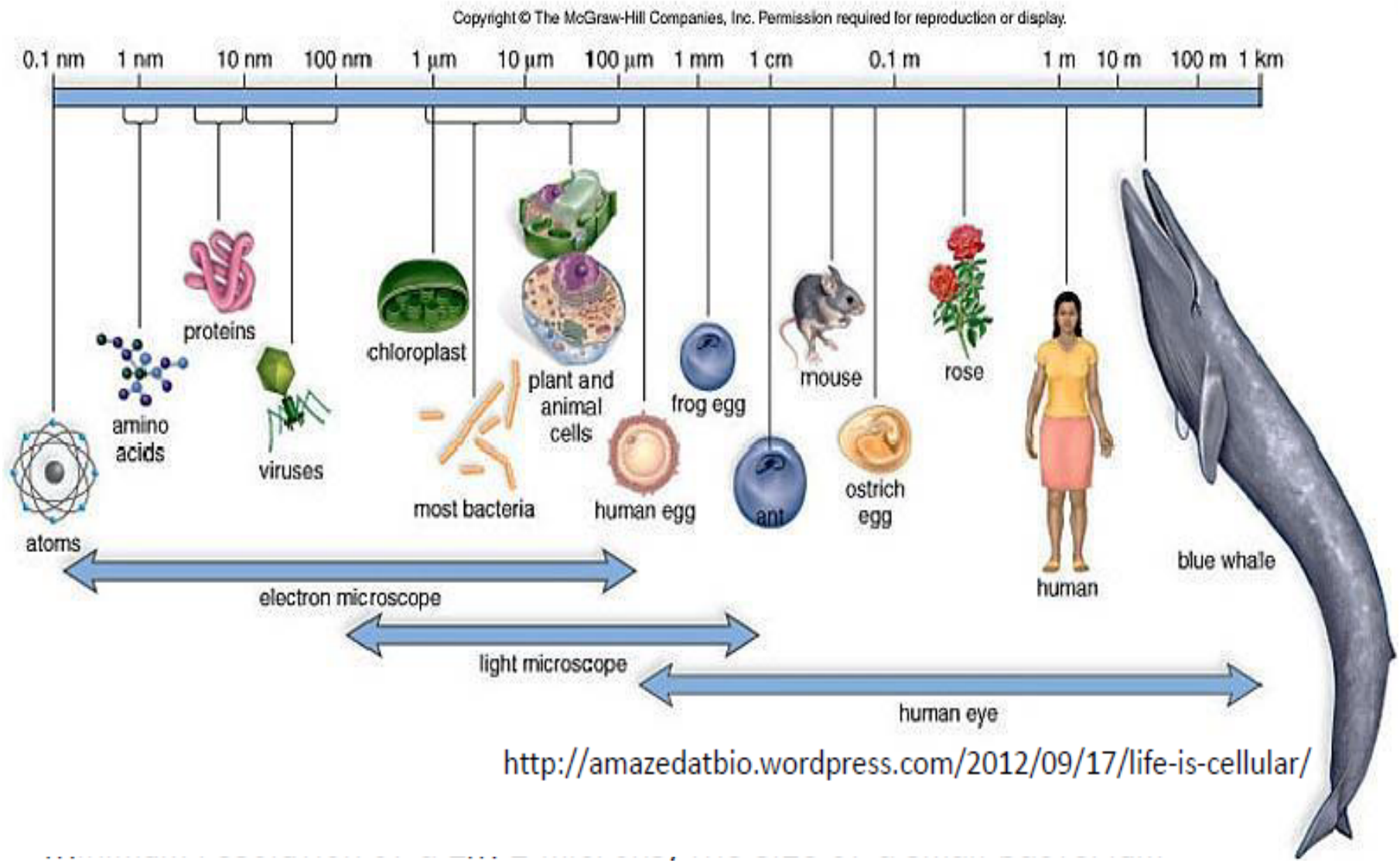
Sperm Cell



Stem cell

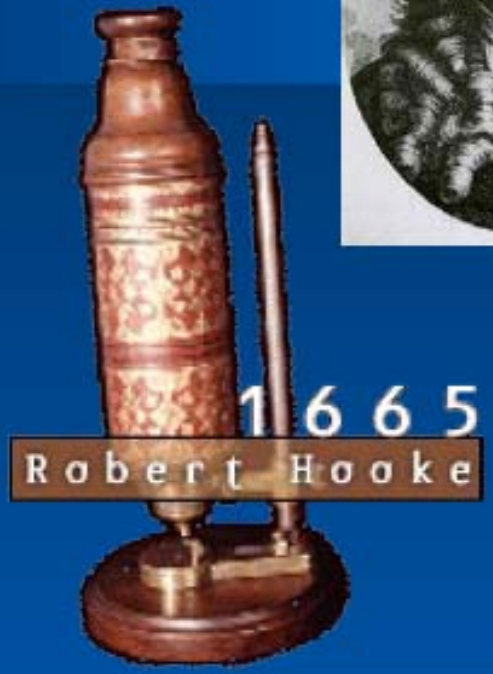
Egg Cell

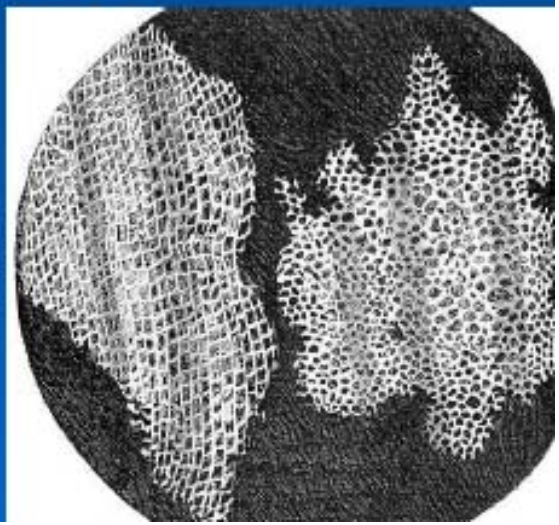
Cell size differs amongst species



Discovery of Cells

- The invention of the lens
- Robert Hooke (1665): observed a thin slice of cork (dead plant cells) with a microscope. He described what he observed as "little boxes" (cells).





Discovery of Cells

- **Anton van Leeuwenhoek (1675): was the first person to observe living cells.**

Overview of cell theory

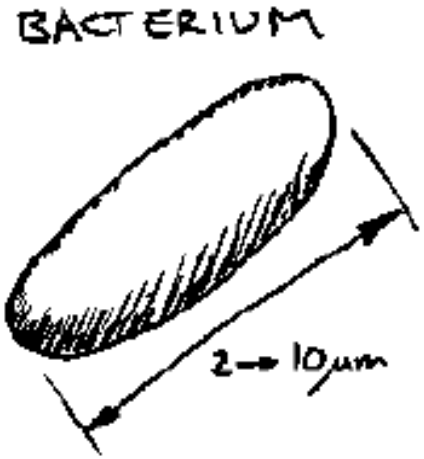
1) Cells are smallest but fundamental and functional unit of life.
2) All living things are composed of cells and all cells are derived from pre-existing cells
3) All basic chemical and physiological functions are carried out inside the cell that keeps us alive.
4) All cells are basically the same in chemical composition and metabolic activities.
5) All cells contain hereditary information (DNA) which is passed on from cell to cell during cell division.
6) Cells shows diversity in size, shape and internal organization
7) Cell size differs among species.

Cell Diversity

- Size
- Shape
- Internal Organization

Cell Diversity- Size

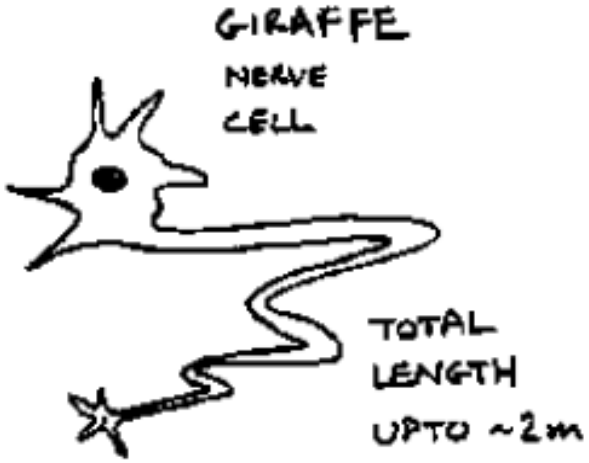
Smallest Cells:



Biggest Cells:

6 inches long, 5 inches wide, 3 pounds

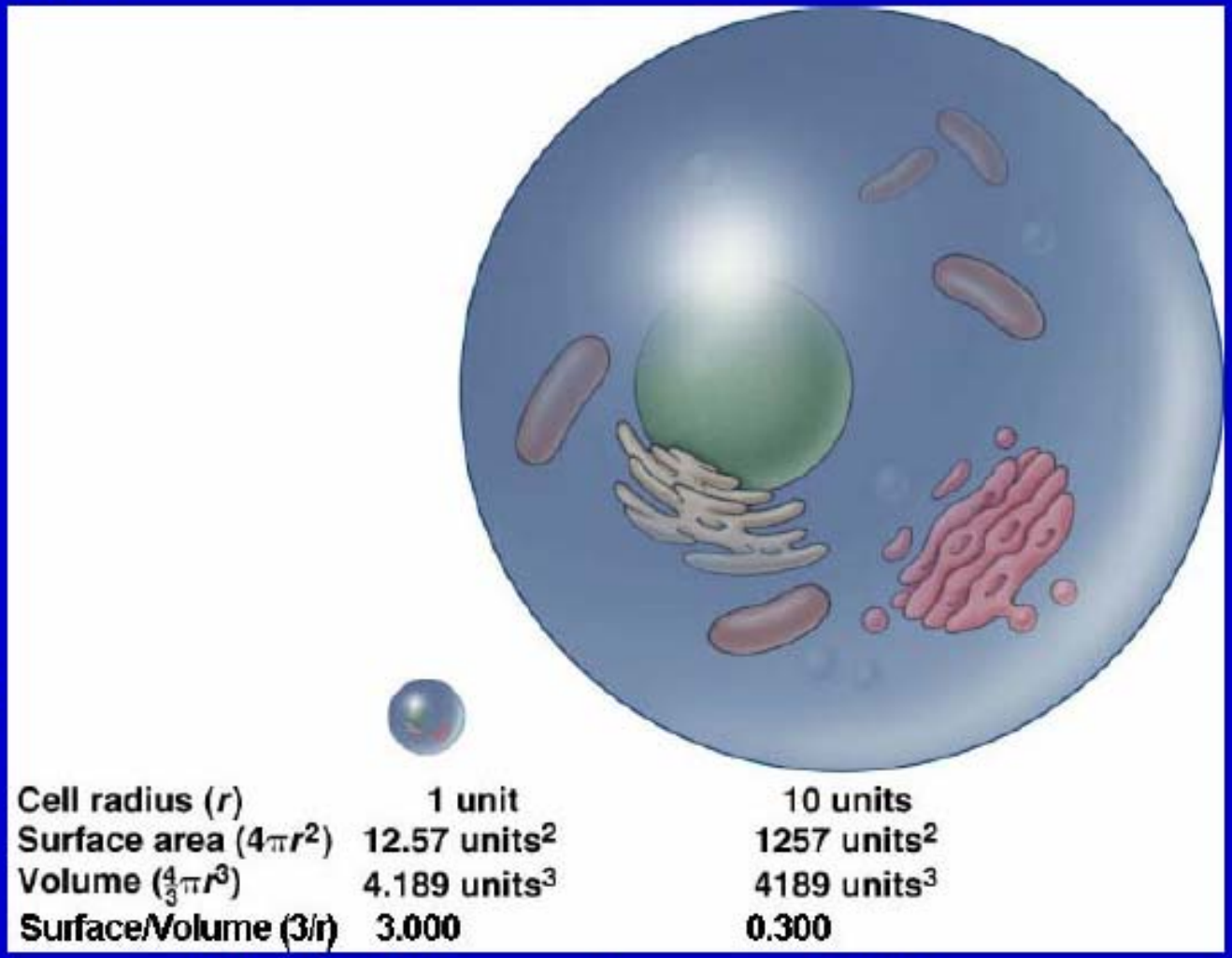
Longest Cells:



Why are cells small?

As cell size increases the volume increases much faster than the surface area.

Cells obtain nutrients, gain information and rid waste through their plasma membrane.

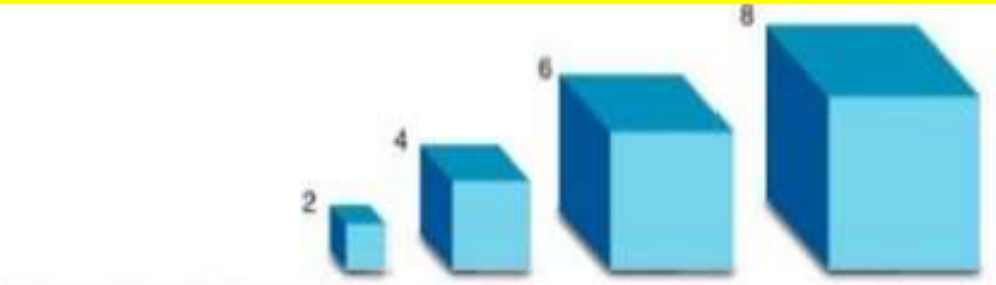


Cell radius (r)	1 unit	10 units
Surface area ($4\pi r^2$)	12.57 units^2	1257 units^2
Volume ($\frac{4}{3}\pi r^3$)	4.189 units^3	4189 units^3
Surface/Volume (3/r)	3.000	0.300

As cell size increases, a cell's ability to exchange with its environment becomes limited by the amount of membrane area that is available for exchange.

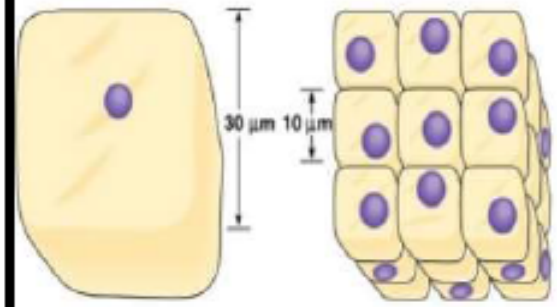
Why cells are smaller in size- concept of surface-volume ratio

Cell size is small to **increase the surface area/ volume ratio** to carry out the efficient exchange of materials between cells and between cells and the environment.



Surface area (square inches)	24	96	216	384
Volume (cubic inches)	8	64	216	512
Surface area/volume	3.0	1.5	1.0	0.75

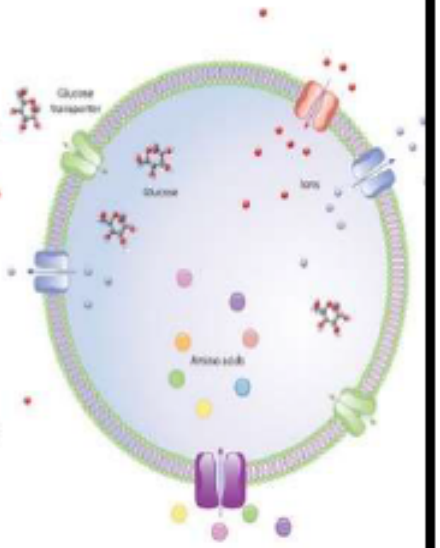
Surface-area to volume ratio too small = decreased rate of chemical exchange ⟹ cell dies



Therefore... in order to build larger organisms, they must be built up from small cell subunits.

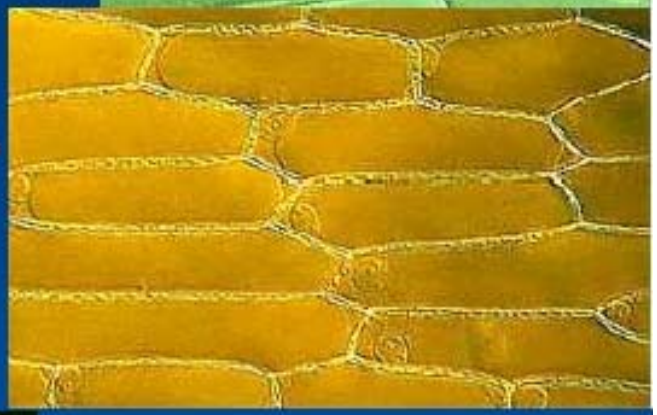
The cell surface (cell membrane) is the site of particle exchange between the inside of the cell and the external environment

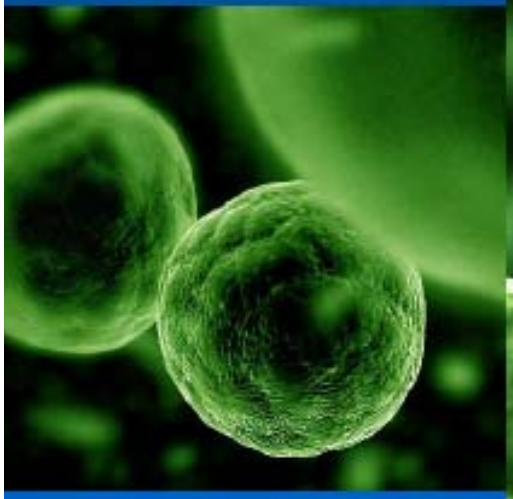
The cell surface must allow for sufficient movement of particles and nutrients into the cell and waste products out of the cell.

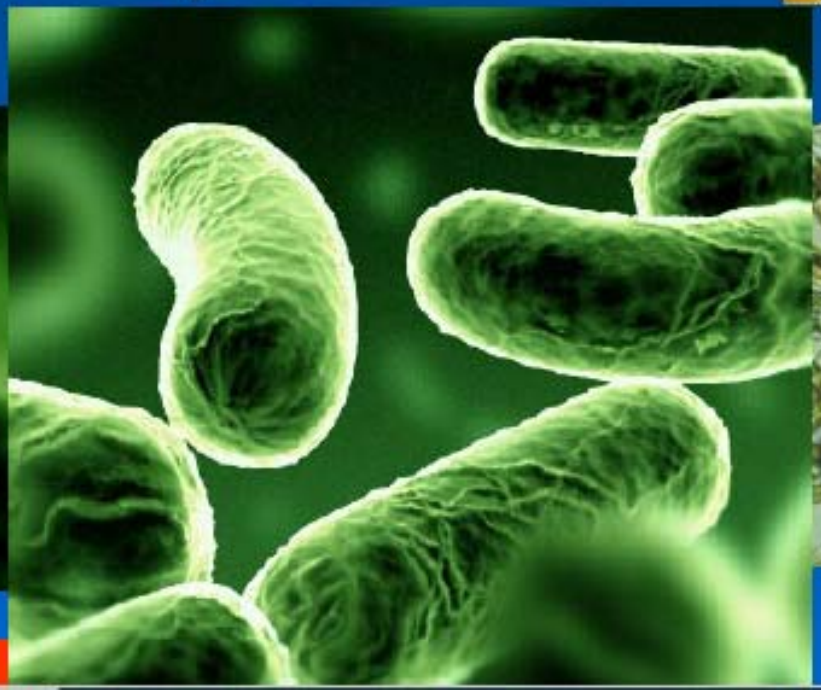


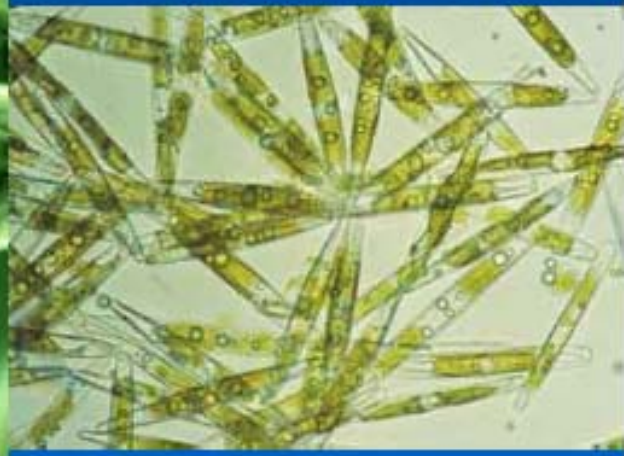
Cell Diversity- Shape

- Cells differ widely in shape.
- Most cells are roughly cuboidal or spherical.

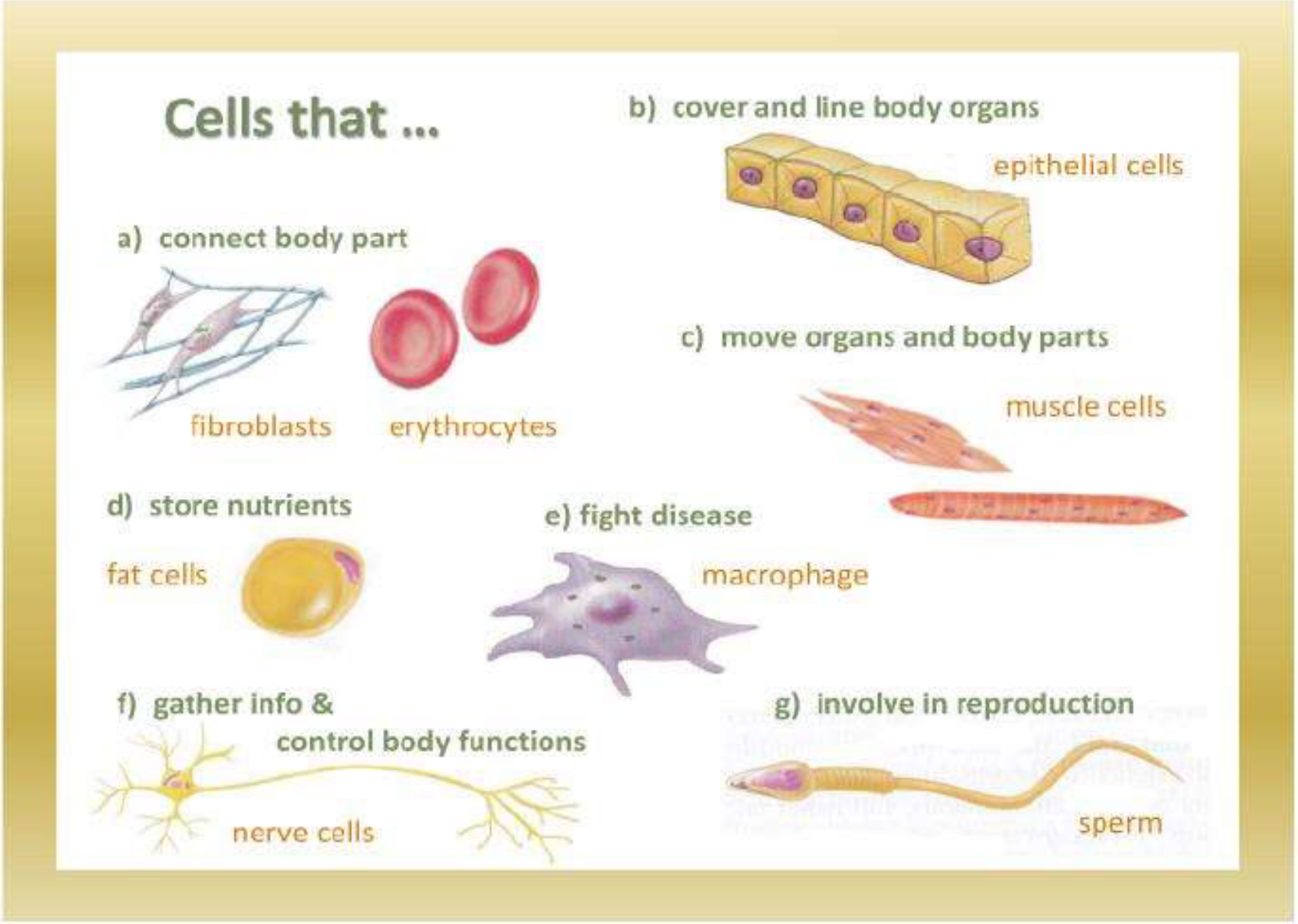








Diverse cell shapes to perform specific functions in body

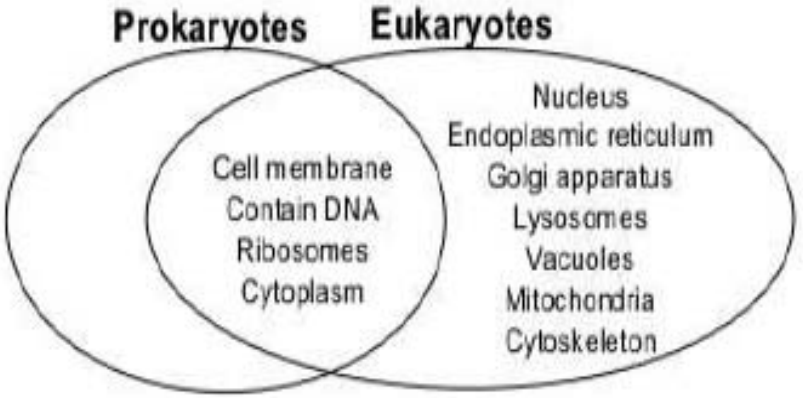


Cells shows diversity in internal organization

- Nucleus: contains DNA which directs the activity of the cell
- Organelle: a cell component that performs specific functions in the cell

Two types of cellular organization- Prokaryotic and Eukaryotic cells depending on their internal organization

- Eukaryotes: cells that contain a nucleus and membrane-bound organelles
- Prokaryotes: cells that lack nuclei and membrane-bound organelles

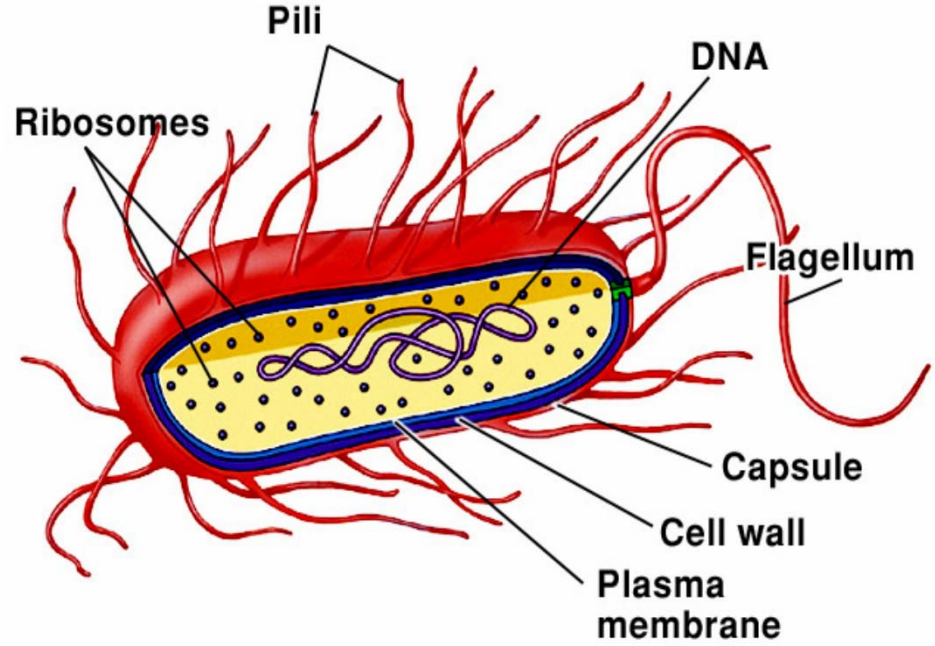


Prokaryotic and eukaryotic cells

Prokaryotic cells - relatively simple cells – lack nuclear membrane and many organelles - bacteria and their relatives are all Prokaryotic.

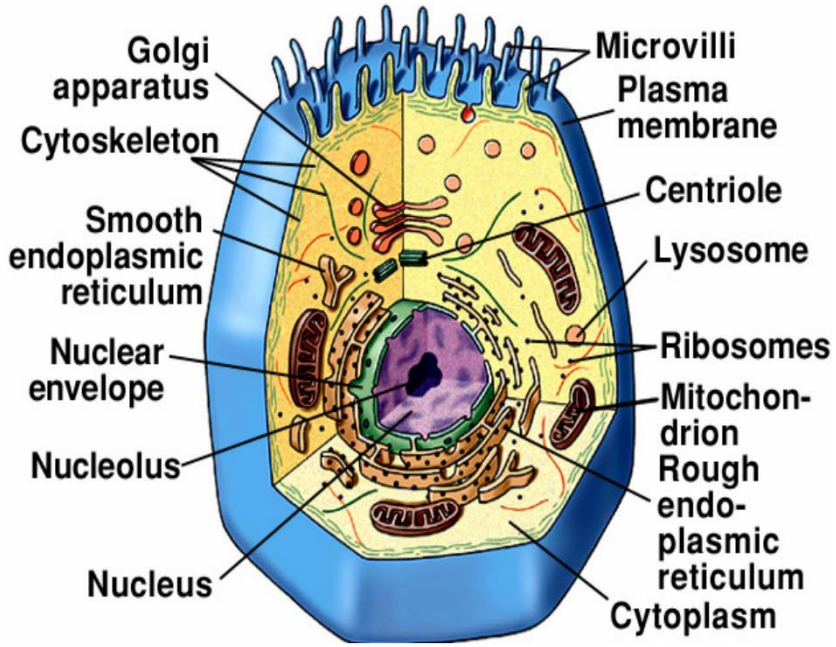
Eukaryotic cells– more complex cells - have a nucleus and many organelles - all cells of plants, animals, fungi, and protists.

Prokaryotic: 1-10 µm
(1 µm = .001 mm)



Prokaryotic cell

Eukaryotic: 10 - 100 µm

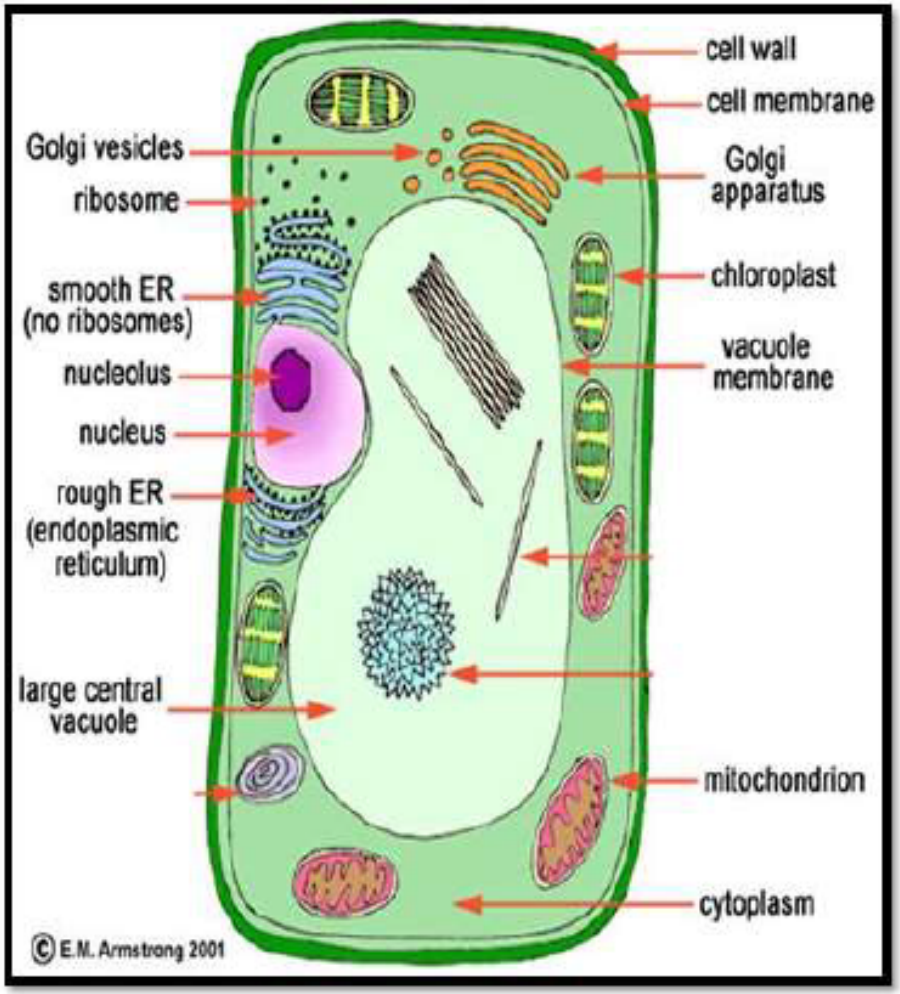


Eukaryotic cell

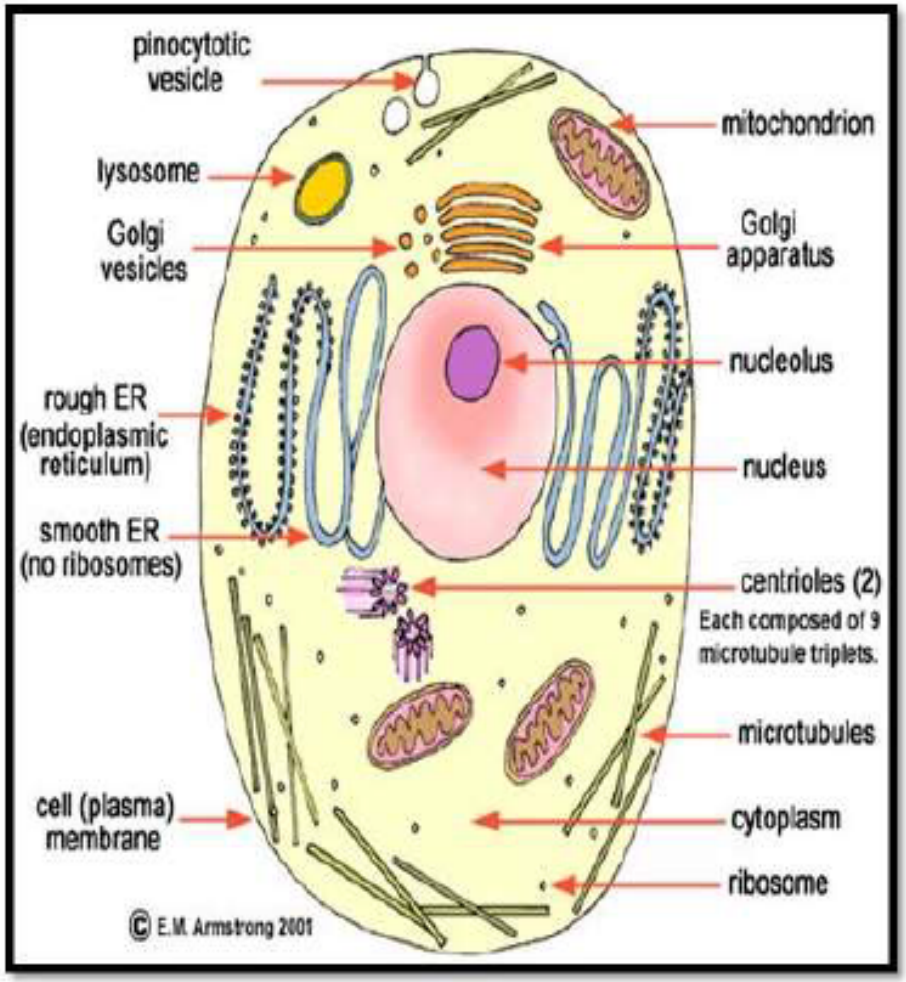
	Prokaryotes	Eukaryotes
nucleus?	NO (nucleoid)	YES
membrane-bound organelles?	NO	YES (Many)
size	1 - 10 µm	10 - 50 µm
when evolved?	3.5 billion years ago	1.5 billion years ago
cytoplasm?	YES	YES
cell membrane?	YES	YES
cell wall?	Some Do	Plants
ribosomes?	YES	YES
DNA?	Circular Free Floating	Chromosomes in Nucleus
examples	Bacteria	Plants, Animals, Fungi, and Protists

Eukaryotic cells- Plant and animal cells are eukaryotic

Plant Cell



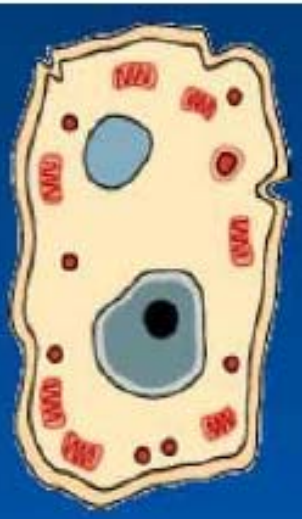
Animal Cell



Animal cells versus plant cells- major differences

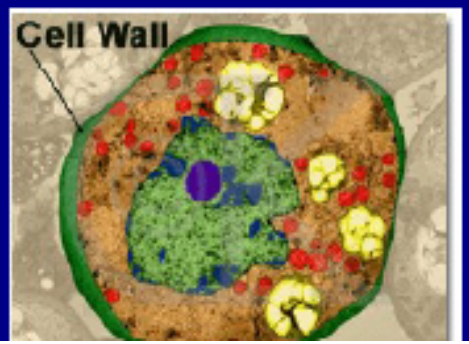
*****No cell wall, no chloroplasts and small vacuoles in animal cells.

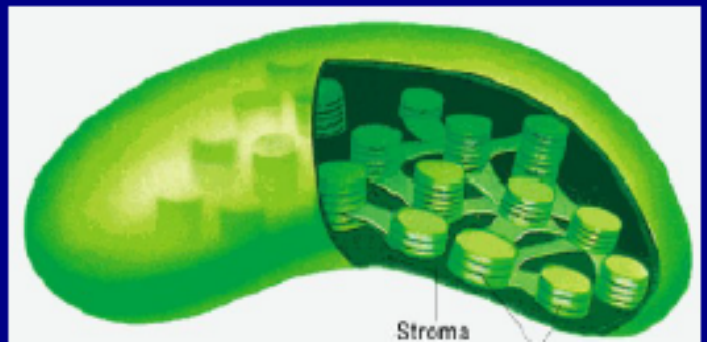
- Animal cells are very similar to plant cells except for the following major differences:
  - Animal cells do not contain chloroplasts
  - Animal cells are not surrounded by cell walls
  - The vacuoles in plants are much larger than those of animals



The three new structures for a plant cell

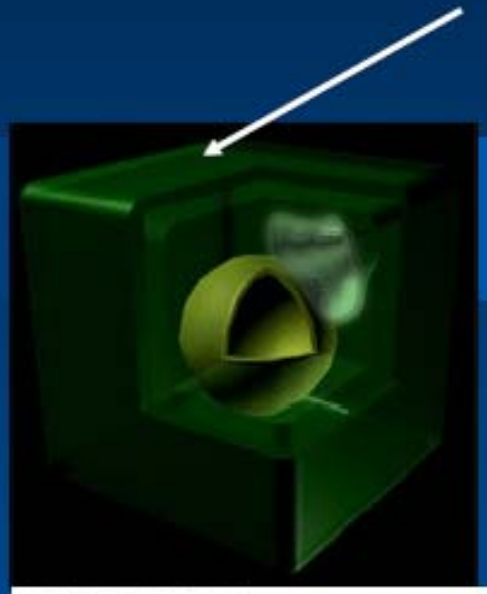
- **Cell Wall**: This wall provides extra support for the cell and gives it a shape. In other words, if there was no cell wall then the cell would have no shape.
- **Chloroplasts**: These make food for the plant. They are green.
- **Chorophyll**: This is very important in making the food for the plant. This structure takes in sunlight and makes sugar for the plant to eat and become green.

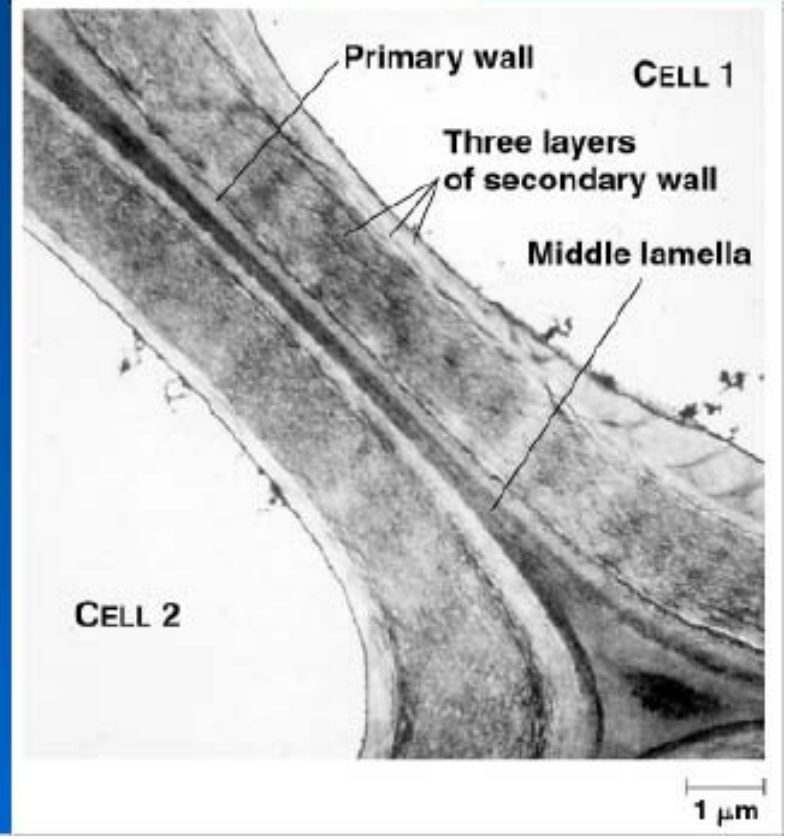




Cell Wall

- Structure: rigid wall made up of cellulose, proteins, and carbohydrates
- Function: boundary around the plant cell outside of the cell membrane that provides structure and support





Plastids – chloroplasts in Plant cells

Plastids

- There are three types of plastids in plant cells:
  - Chloroplasts (discussed on next slide)
  - Chromoplasts: synthesize and store pigments
  - Leucoplasts: store food such as starches, proteins, and lipids

Chromoplasts

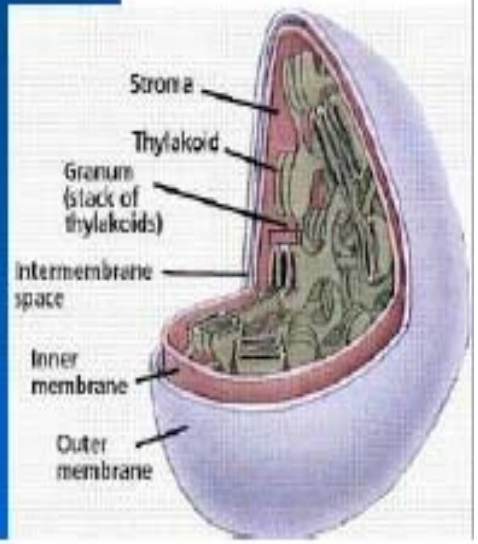
Red Pepper

Flower

Leucoplasts

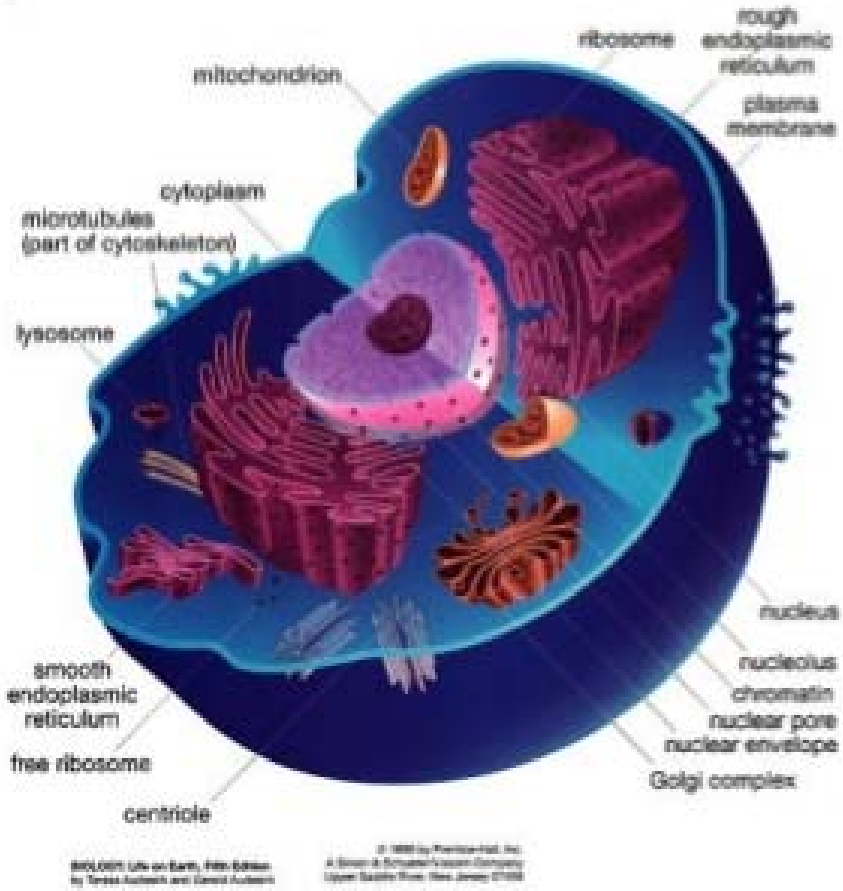
Chloroplasts

- Structure: stacked sacs (thylakoids) that contain chlorophyll surrounded by a double membrane
- Function: photosynthesis (conversion of light energy to chemical energy stored in the bonds of glucose)



Cell Organelles

- Organelle= "little organ"
- Found only inside **eukaryotic cells**
- **Organelles are structures that have specific jobs within cells**
- All the stuff in between the organelles is cytosol
- Everything in a cell except the nucleus is cytoplasm



- **A typical animal cell consists of following Cell organelles:**

1) Plasma membrane
2) Cytoplasm
3) Nucleus
4) Endoplasmic reticulum
5) Golgi body
6) Lysosomes
7) Peroxisomes
8) Mitochondria
9) Cytoskeleton
10) Centrosome and centriole
11) Vacuoles
12) Ribosomes

Plasma membrane

1) Physical properties of plasma membrane

a) Selectively permeable: The plasma membrane is selectively permeable to certain ions and molecules. Most of the substances are impermeable through plasma membrane. However, presence of specific proteins which act as carriers and transporters allow few substances to pass through.

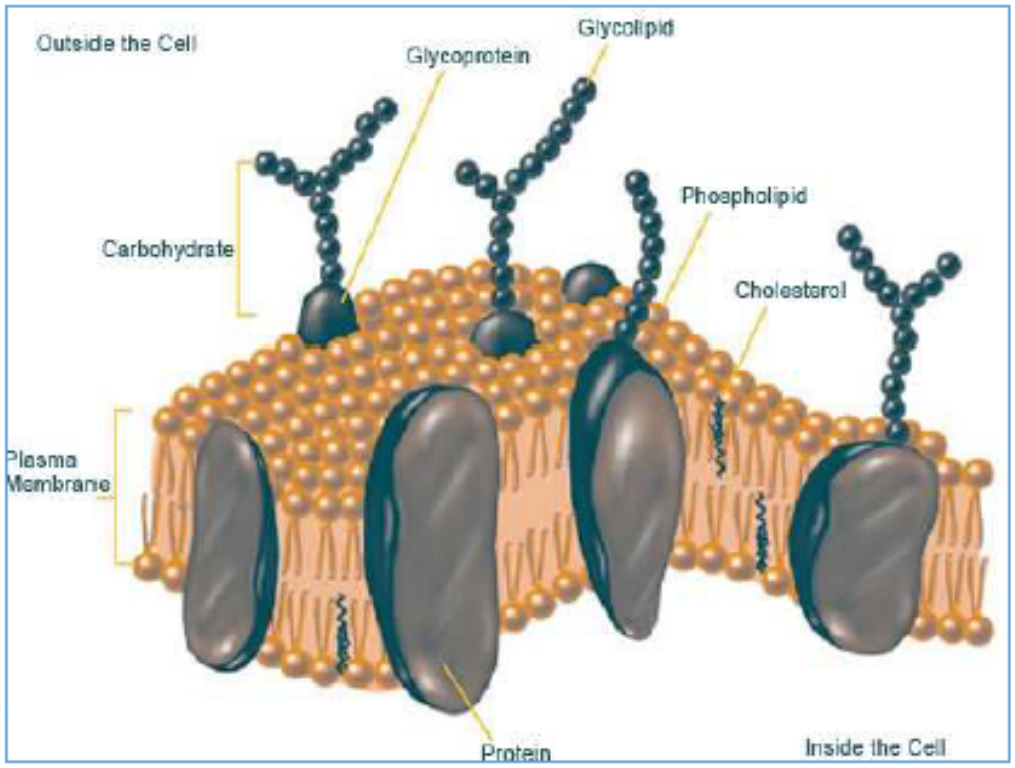
b) Plasma membrane can have extensions such as axons and dendrites are the extension of plasma membrane. Axon of neuron cell is the longest extension of the plasma membrane. Cilium is the plasma membrane extension found in the microvilli of small intestine where absorption of food takes place.

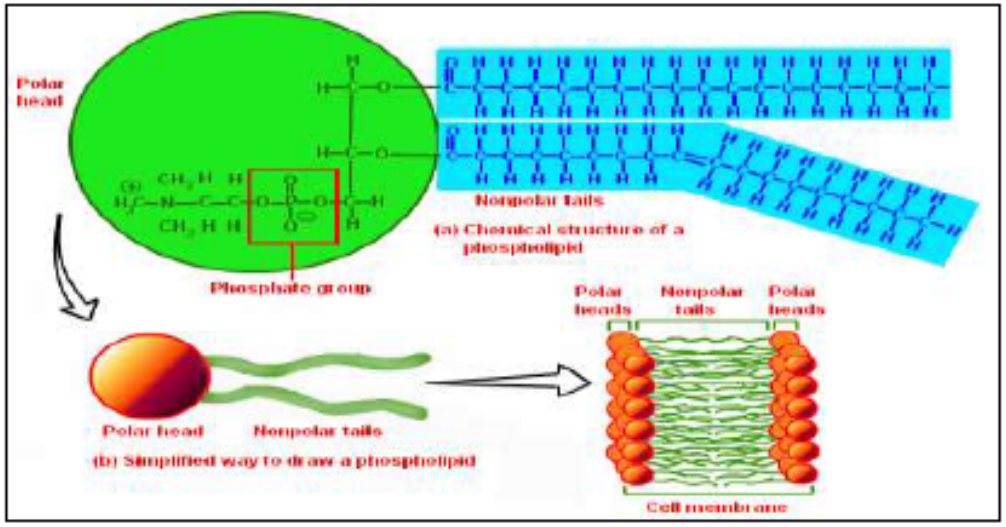
c) Allows communication with other cells.

d) Structural, keeping the cell contents together.

2) Plasma membrane is amphipathic in nature, composed of phospholipids

The phospholipids are arranged in two layers called **phospholipid bilayer-** one is outer layer and other is inner layer. **The outer layer is called outer leaflet. The inner layer is called inner leaflet.** Each phospholipid has **a polar head- which gives it a hydrophillic property and a non-polar tail which is a fatty acid tail giving it a hydrophobic property. This kind of property of having both hydrophobic and hydrophilic region is called Amphipathic.** The hydrophillic heads of the outer layer faces extracellular fluid and hydrophillic heads of the inner layer faces cytoplasmic fluid.





Plasma membrane cont.

Membrane Lipids: 3 classes of lipids (Amphipathic molecules)

- **Phospholipids:** Most abundant, derivative of glycerol 3-phosphate

Ex: Phosphatidylcholine, phosphatidylinositol, phosphatidic ethanolamine, plasmalogens

- **Sphingolipids:** derived from amino alcohol, sphingosine

Ex: Glucosylcerebroside, Sphingomyelin, gangliosides

- **Steroids:** four ring hydrocarbon containing lipids

Ex: Cholesterol

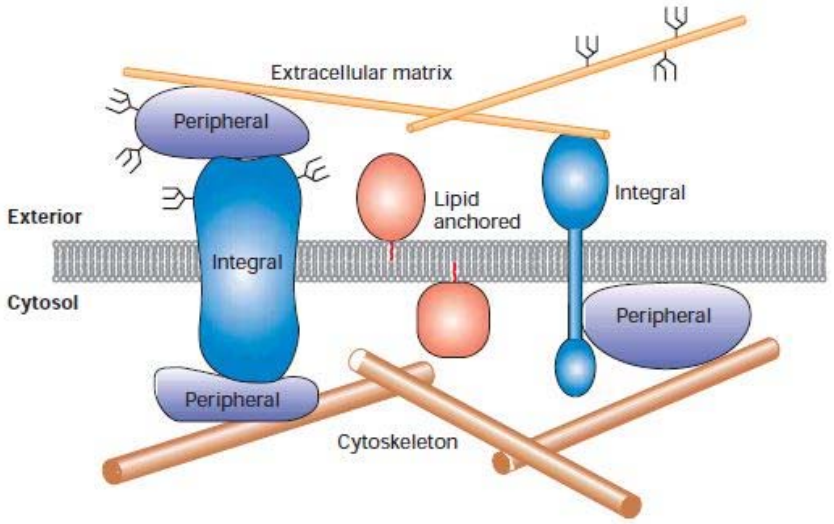
Asymmetrical distribution of lipids between the inner and outer leaflets. Meaning is that, lipid molecules present in the outer leaflet and the inner inner leaflets are not same. For example, **phosphatidylcholine and sphingomyelin** are preferably located in the outer layer. Whereas, **phosphatidylethanolamine and phospahtidylserine** are mainly located in the inner leaflet.

Plasma membrane cont.

Membrane Proteins

- Cell membranes often contain proteins embedded within the phospholipid bilayer.

- Proteins help move large molecules or aid in cell recognition (peripheral and integral)



Integral membrane protein: Transmembrane protein, span a phospholipid bilayer and built of 3 segments
Ex: Glycophorin A, bacteriorhodopsin, porins, ion channels

Lipid anchored proteins: bound covalently with one or more lipid molecules, which acts as a anchor
Ex: Ras proteins, rab proteins

Peripheral proteins: Non-covalent binding, localized either in exoplasmic or cytosolic side of plasma membrane
Ex: Pleckstrin, phospholipase, lamins

Cytoplasm

1) **Cytoplasm:** The region of the cell that is within the plasma membrane includes the fluid, the cytoskeleton, and all of the organelles except the nucleus is called the cytoplasm.

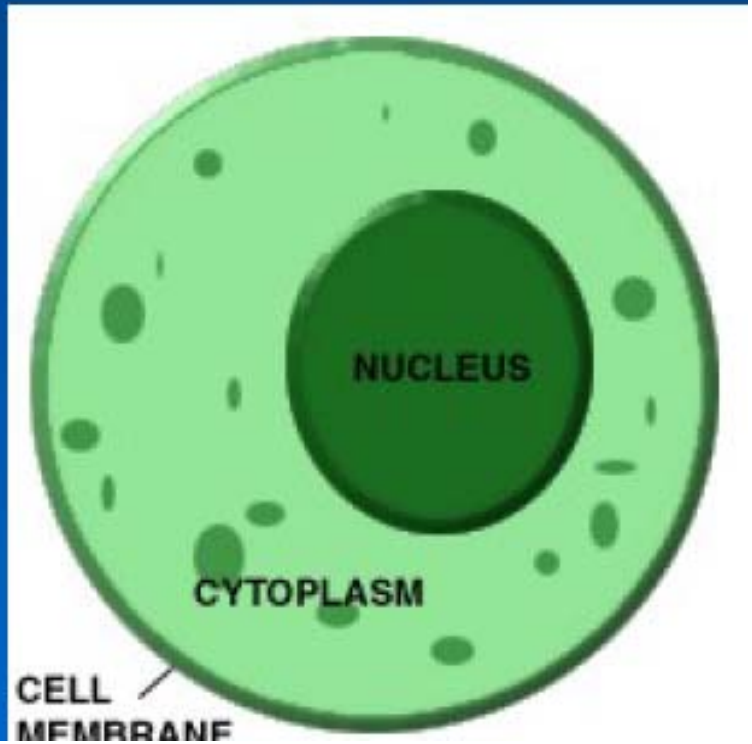
2) The part of the cytoplasm that includes molecules and small particles, such as ribosomes, but not membrane bound organelles is the cytosol. The cytosol surrounds the organelles and account for about 55 % of the total cell volume.

3) **Cytosol:** About 20% of the cytosol is made up of protein and contains 75-90% water and various dissolved solutes and suspended particles. Among these are various ions, glucose, amino acids, fatty acids, proteins, lipids, ATP, and waste products. The cytosol is the site of many chemical reactions that maintain cell structures and allow cellular growth.

Cytoplasm

- **Structure: gelatin-like fluid that lies inside the cell membrane**
- **Function: -contains salts, minerals and organic molecules**

  -surrounds the organelles



Nucleus

1) Largest organelle in animal cell and composed of following parts:

a) **Nuclear membrane** is the double membrane, containing many different types of proteins in the membrane.

Nuclear membrane has the outer membrane that is continuous with the rough endoplasmic reticulum (RER) and inner membrane is continuous with the space called lumen of the RER.

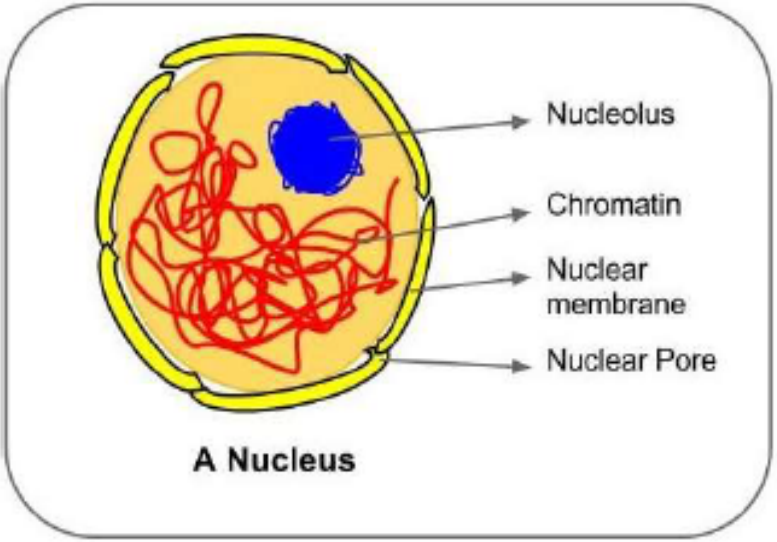
b**) Nuclear pore** is the region where the outer and inner nuclear membrane fuses. The region contains "specific protein complexes" acting as gatekeeper for entry of materials in and out of the nucleus.

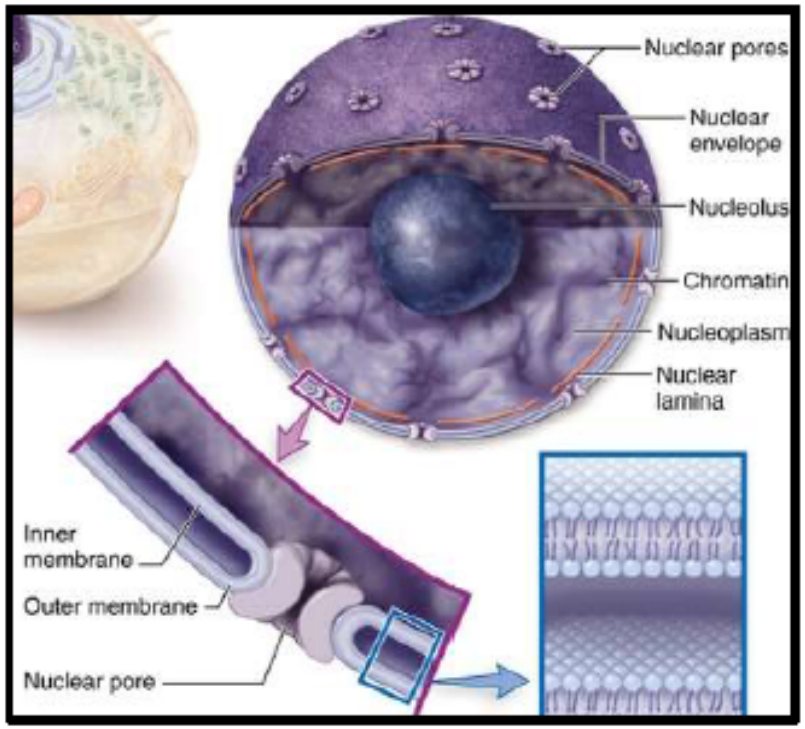
c) Nucleolus. It is the dense region inside the nucleus which is without membrane, and site for ribosomal RNA (rRNA) and transfer RNA (tRNA) synthesis. DNA is concentrated in the process of rRNA synthesis.

d) Nucleoplasm. The non-nucleolar portion of the nucleus that contain condensed **concentrated DNA.**

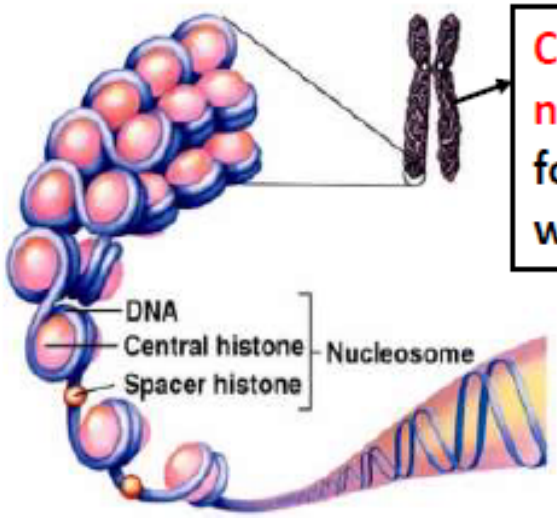
*****Function of the nucleus**: Head of the cell as it directs the cellular activities. It contains genetic material DNA in the chromosomes.

Structure of Nucleus and DNA





Chromatin in nucleus: chromatin is DNA as a thread-like material



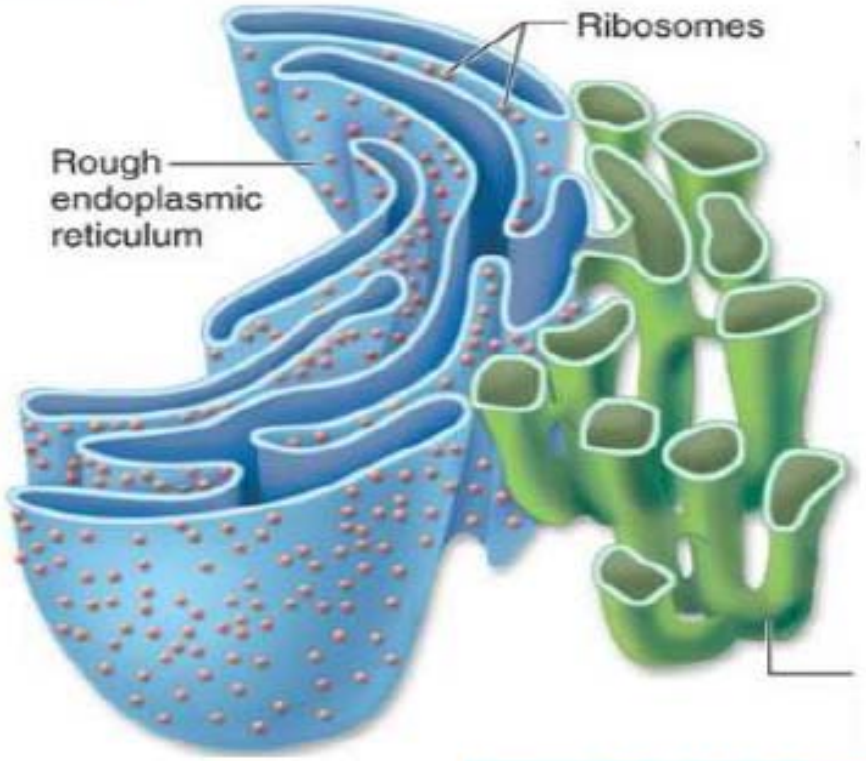
Chromosomes in nucleus: condensed form of chromatin when cells divide

Endoplasmic reticulum

1) Largest membrane in eukaryotic cell. They exists as closed, flattened membrane-bound sacs.

a) Rough endoplasmic reticulum (RER) has ribosomes attached in them giving them rough appearance.
Smooth endoplasmic reticulum (SER) has no ribosomes

b) RER is present near the nucleus and continuous with the outer membrane of the nuclear envelop.



RER

SER

RER functions:

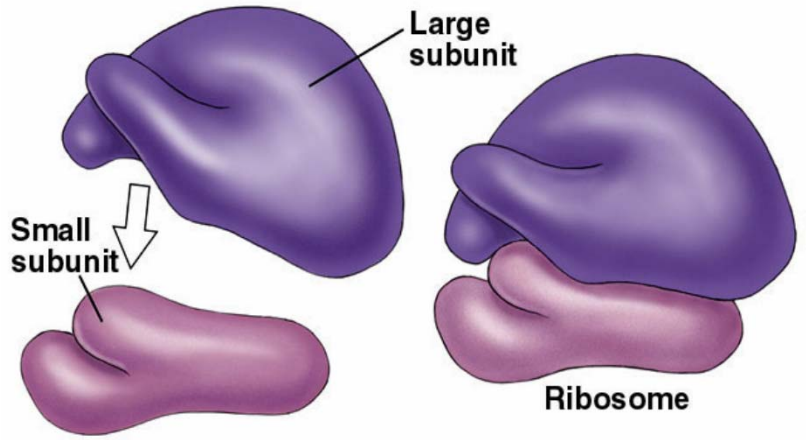
1) Major site for **Protein synthesis**. Synthesize membrane proteins, organelle proteins and secretory proteins.
2) Abundant in cells that are actively involved in secreting specific proteins such as antibodies, digestive enzymes, insulin hormone.
3) Plasma cells secrete antibodies, pancreatic aciner cells produces digestive enzymes such as pancreatic enzymes, islets of Langerhans in pancreas secrete insulin and glucagon. Cytosol of these cells are highly filled with RER and its secretory vesicles.

SER functions

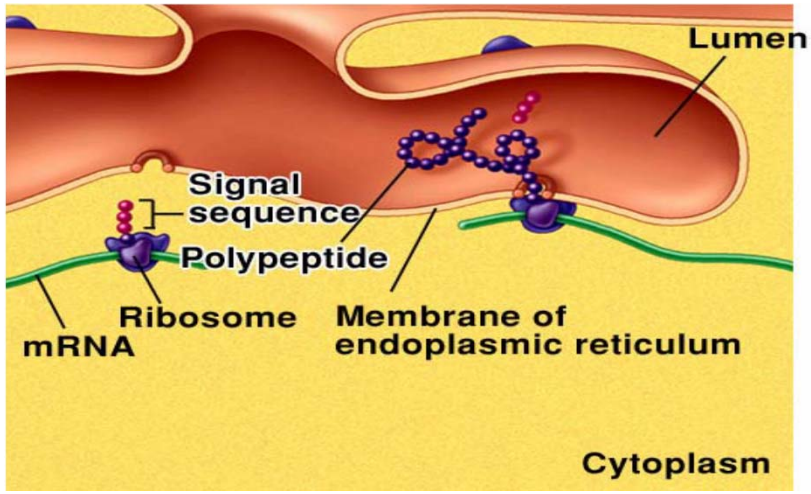
- **Synthesize fatty acids and phospholipids**.
- Contain certain enzymes **which detoxify chemicals** such as pesticides and converting them into water soluble conjugated products that can be secreted from the body. **Abundant in liver cells.**

Ribosome

Ribosomes are either free or attached to the rough ER and play a role in protein synthesis.



- Made of protein and rRNA molecules
- Two subunits - large and small - each made of protein and ribosomal RNA (rRNA)
- Subunits associate when they are synthesizing proteins



- Ribosome assembly begins in the nucleolus and is completed in the cytoplasm

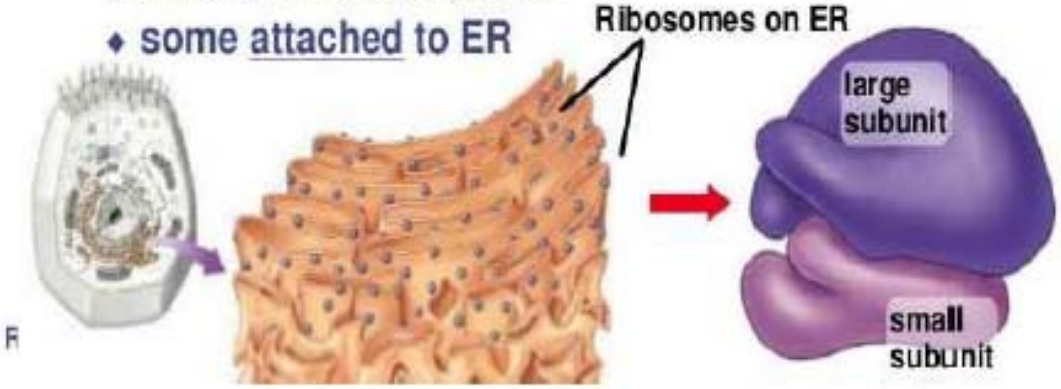
- rRNA is synthesized in the nucleolus

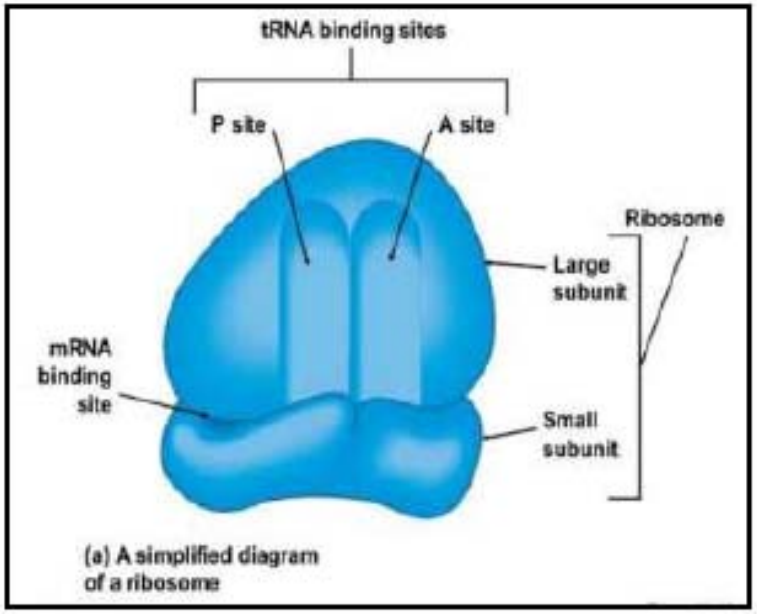
- Protein synthesis occurs on ribosomes that are free-floating in the cytoplasm and on ribosomes attached to endoplasmic reticulum (ER)

Ribosomes- attached with RER

Ribosomes

- Function
  - protein factories
  - Eukaryotes have 80S, prokaryotes 70S
  - read instructions to build proteins from DNA
- Structure
  - 2 subunits
  - some free in cytoplasm
  - some attached to ER





Golgi apparatus

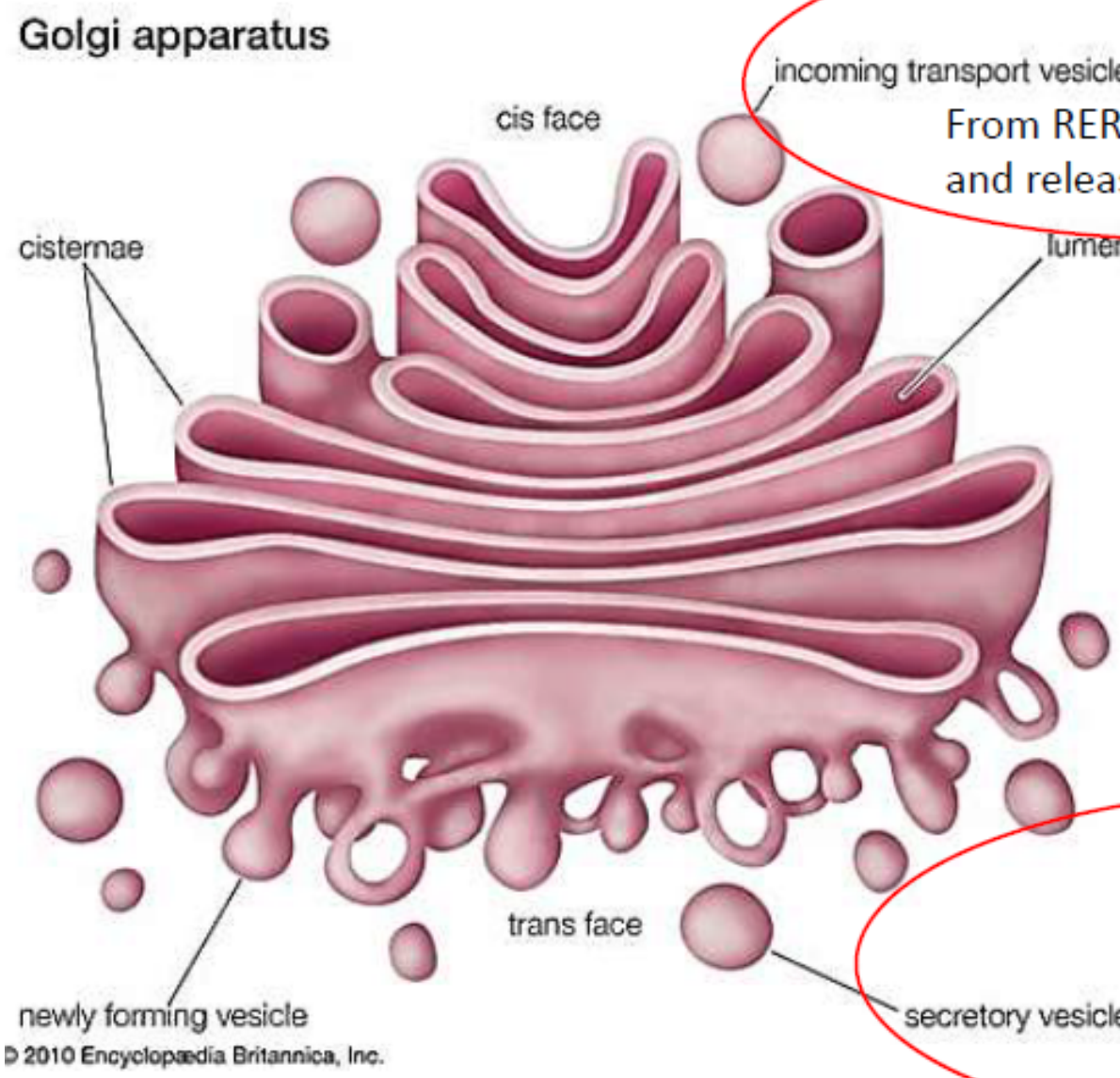
1) Golgi body are made up of flattened membrane bound sacs **called as cisternae.**

2) **Cisternae** forms stack. Stack has three defined regions- **cis, medial and trans**.

3) Golgi body is the "**sorting center of the cell**". In other words, they are involved in **collection, packaging and distribution of proteins to different parts of the cell**. This is done by modifying proteins which are synthesized in RER. Modification of **protein involves posttranslational modification such as adding sugar residues to the protein forming glycoproteins, proteoglycans.**

4) **Secretory vesicles** budded off from RER fuse with the cis region of Golgi body where they deposit their contents. They are then transferred to medial to trans region. Each region contains specific enzymes that modify proteins to be secreted and membrane proteins differently depending on their structure and their final destinations (meaning whether they have to be in the membrane in the form of transporter, channels, enzymes or remain in the cytoplasm).

Golgi apparatus structural view



From RER fuse with the cis region and release the materials

Medial region of golgi where enzymes modifies the synthesized proteins

Trans face secretory vesicles: Carry modified materials/processed proteins and transported to final destinations

Mitochondria

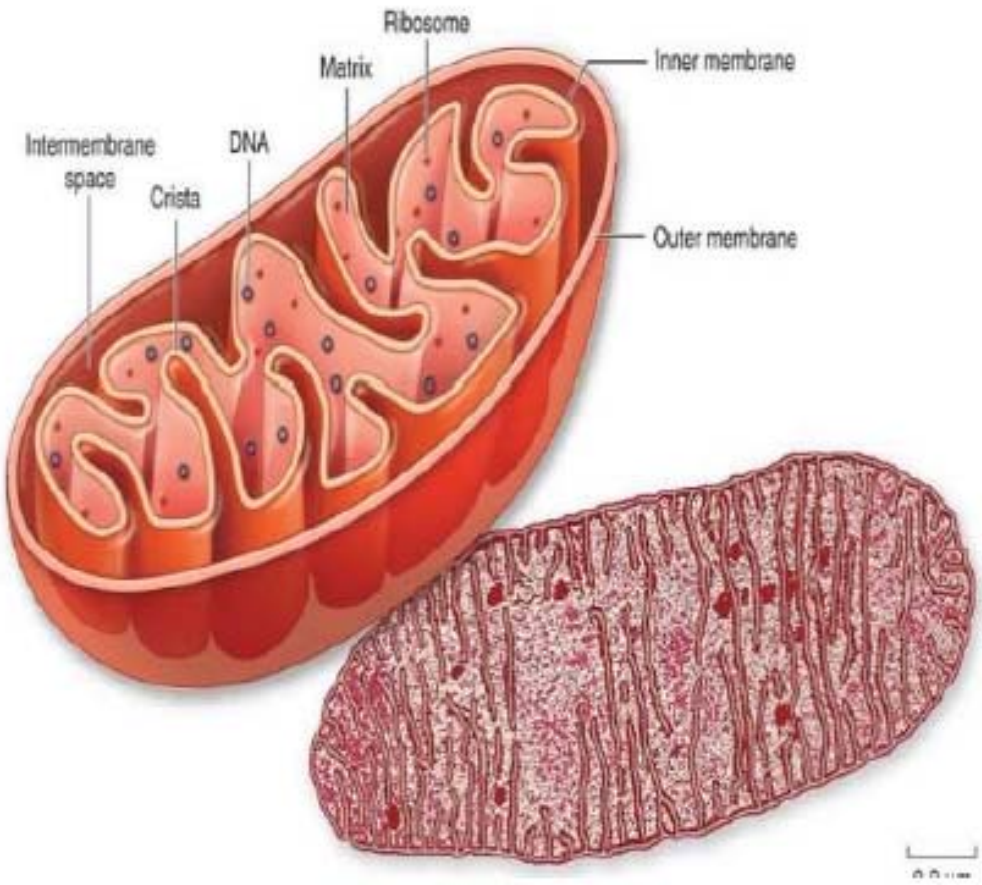
1) **Mitochondria are known as power house/power plant of the cell involved in cellular respiration**.

This is because they are the main center for generating ATP molecules which are the energy molecules. Glucose absorbed by the cell undergoes aerobic degradation within the mitochondria producing ATP molecules. **This is also called cellular respiration**. One glucose molecule generates 30 ATP molecules.

$$\textbf{1 molecule of Glucose} + O_2 \rightarrow CO_2 + H_2O + \textbf{30 ATP}$$

2) **Mitochondria are self-duplicating organelle** because it contains its own DNA which codes for several proteins that are required for mitochondria itself. 25% cell volume is occupied by mitochondria.

Mitochondria structure



1) Mitochondria are made up of two membranes. The outer membrane is composed of 50% lipids and 50% proteins. The **inner membrane has infoldings** or projections called as **cristae** and has 20% lipids and 80% proteins. The inner membrane is the site of ATP production through the **process of oxidative phosphorylation and electron transport chain**.

2) Intermembrane space: the space between two membranes of mitochondria is intermembrane space.

3) Mitochondrial Matrix: the central space where the cristae lies is called the mitochondrial matrix. The matrix contains **ribosomes and DNA.**

SITE OF SEVERAL METABOLIC REACTIONS

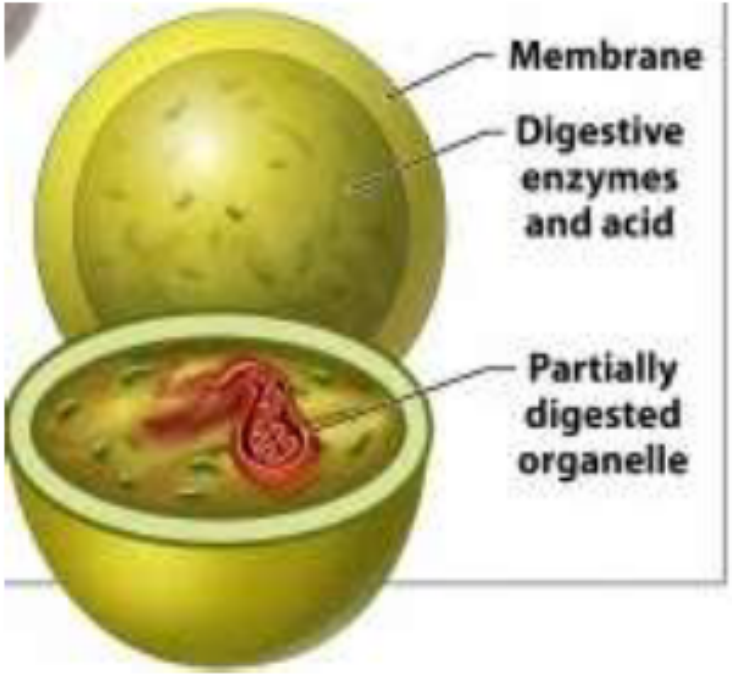
- OUTER MEMBRANE — Oxidation of epinephrine
  Degradation of tryptophan
  Elongation of fatty acid
- INNER MEMBRANE — Oxidative phosphorylation
- MATRIX — Kreb's cycle
  Beta oxidation
  Detoxification of ammonia in urea cycle
  Storage of calcium ions.

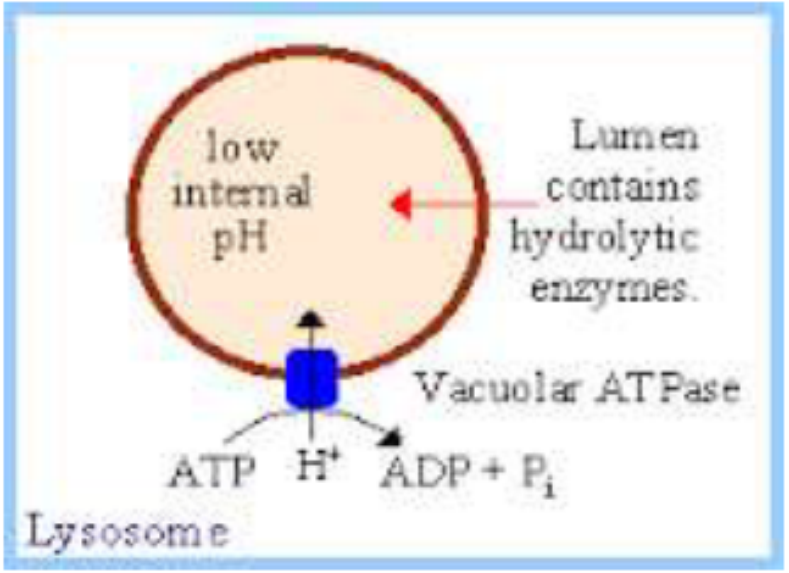
Lysosomes

1) Called as **"Digestive plant of the cell". In simple words, lysosomes recycle cellular waste products and consumed material**
2) Exclusively found in animal cell.
3) They are single membraned small vesicles containing digestive enzymes to break down macromolecules such as proteins, lipids, carbohydrates, nucleic acids.
4) **"Autophagy"** means eating oneself. **Lysosome degrade damaged, or unnecessary cell organelles such as an aged mitochondria and other cell constituents.** The alternate source of intracellular building blocks and substrates are regenerated for new cell formation.
5) **Example: the tail of a tadpole, which is destroyed to make tailless frog.**

Lysosomes structural view

6) Lysosomes degrade material that is internalized by the cell membranes such as bacteria or other germs or other foreign materials. **The internal environment of lysosome is acidic that is pH is 4 to 5. The low internal pH is maintained by vacuolar ATPase that actively pumps H^+ ions.** Enzymes that are functional in this pH are hydrolytic enzymes called **Hydrolases** (eg. Nucleases that degrade RNA and DNA), **proteases** (degrade variety of proteins and peptides), **acid phosphatases** (remove phosphate group from mononucleotides).



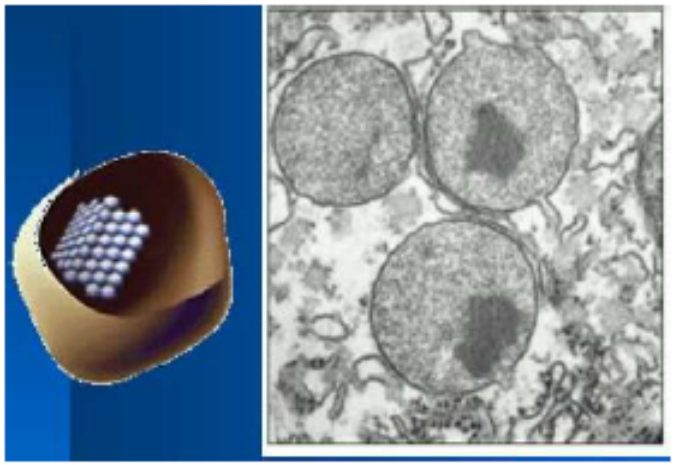


Peroxisomes

1) **Single membrane**-bound organelles found in all types of animal cells except RBCs (Red Blood Cell).

2) Function: i) **Detoxification** of various toxic molecules for example alcohol. ii) **Break down of fatty acids** to produce acetyl groups that are transported into the cytosol and used in the synthesis of cholesterol and other metabolites.

3) Contains **oxidases** and **catalase enzymes**. These enzymes use molecular oxygen to oxidize organic substances. For example, beta oxidation of fatty acids. In such oxidative processes, hydrogen peroxide (H_2O_2) is formed in the body, which is very corrosive and poisonous substance. However, **catalase** enzyme is abundant in peroxisome which converts hydrogen peroxide into water and oxygen.



Cytoskeleton

a) **Cytoskeleton of the cell exists as cytoskeletal fibres** that form networks and bundles that support cellular membranes, help organize organelles and participate in cargo movement, and cell movement.

b) **Three kinds of cytoskeletal fibres** are found within the cell:

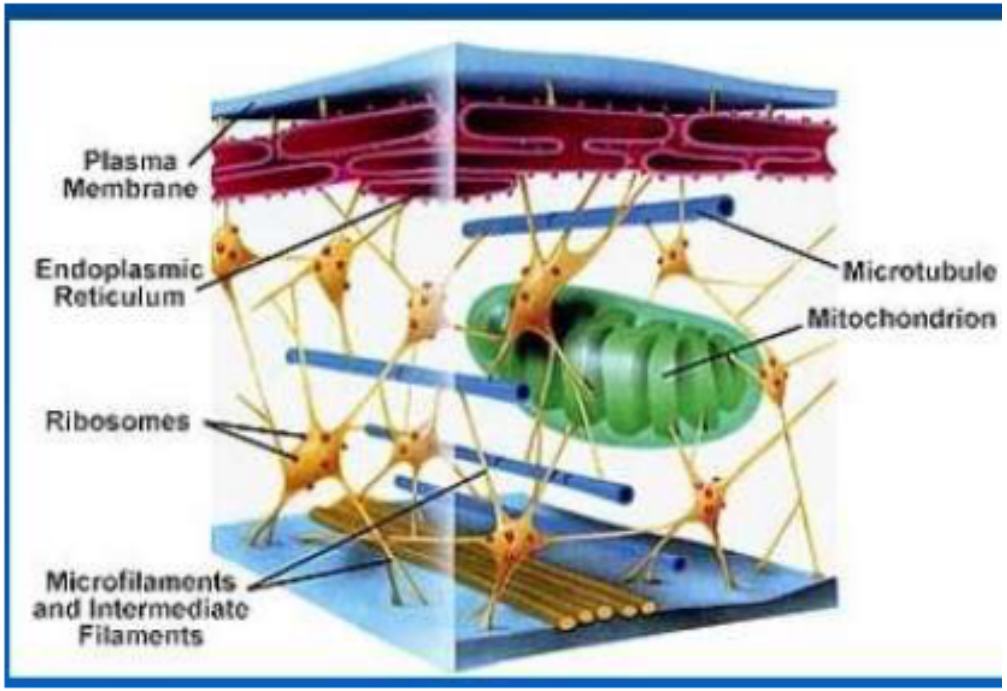
i) Microfilaments. Appearance as **two interwined strands**. They are made up of actin protein and therefore also known as actin filaments. **Actin forms core of the microvilli (finger-like projections in the intestinal epithelial cells for absorption of molecules).** The other kind of plasma membrane projections also have actin filaments. Also present in **dendrites and axon of a neuron**. Role of actin is structural support and various intracellular movements.

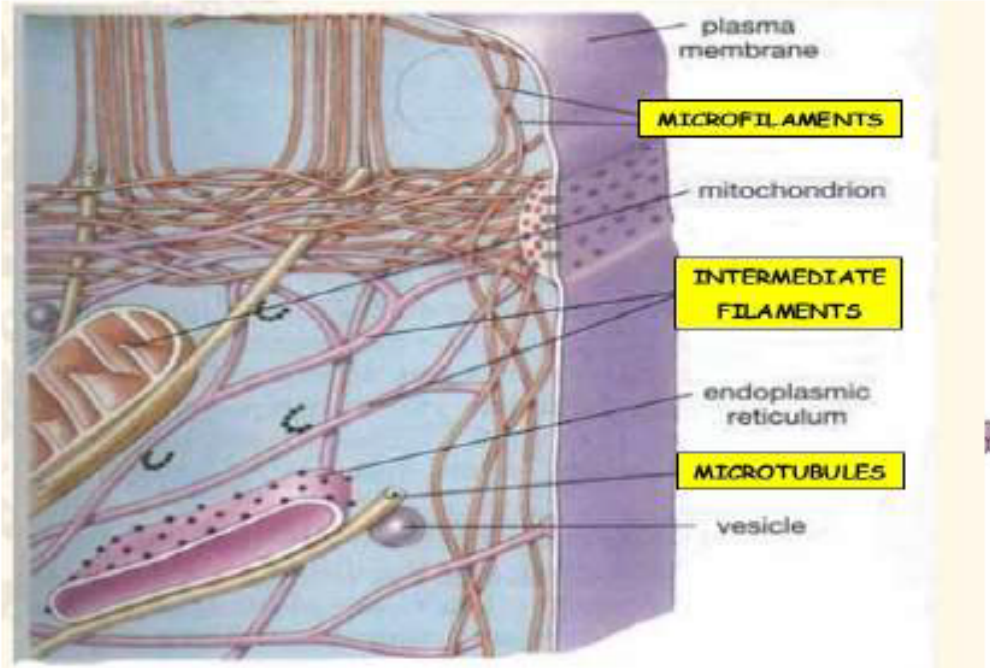
ii) Microtubules. Appearance as kind of **hollow tubes**. They are made up of **alpha-tubulin and Beta- tubulin monomers**. Their important functions are to support the cell, organelle movement within the cell, and during cell division they help movement of chromosomes.

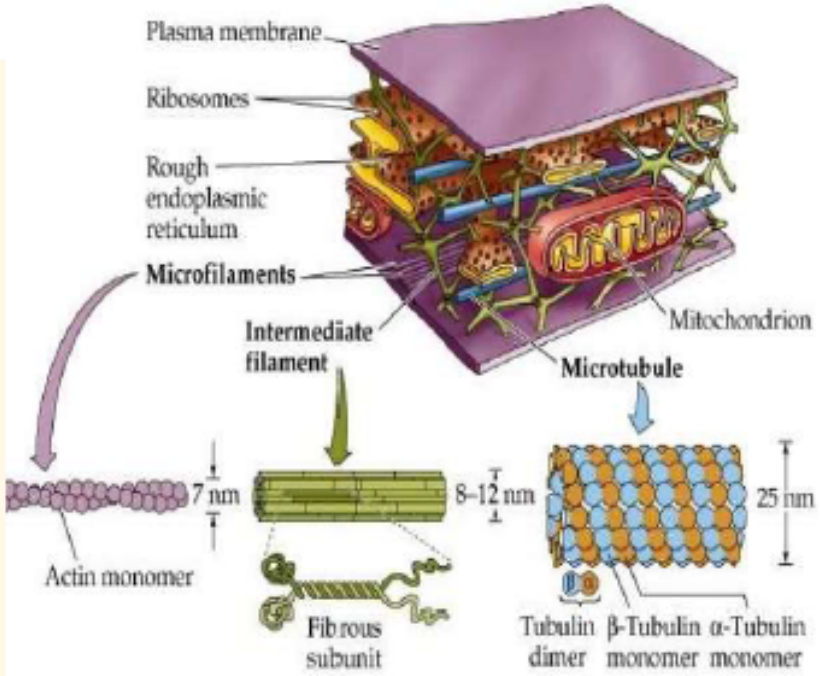
iii) Intermediate filaments. They are fibrous proteins supercoiled into thick cables. Important functions are support for nucleus, formation of nuclear lamina, cell adhesion.

iv) Overall function of cytoskeleton are: cell shape, organelle movements, cell motility, cell polarity, chromosomes movement.

Cytoskeleton structural view

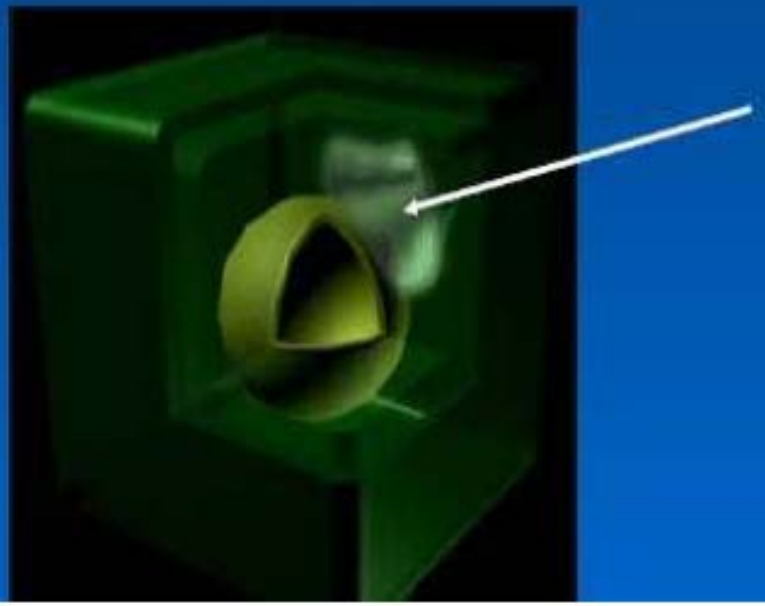






Vacuoles

- Structure: a sac of fluid surrounded by a membrane
  - Very large in plants
- Function: used for temporary storage of wastes, nutrients, and water

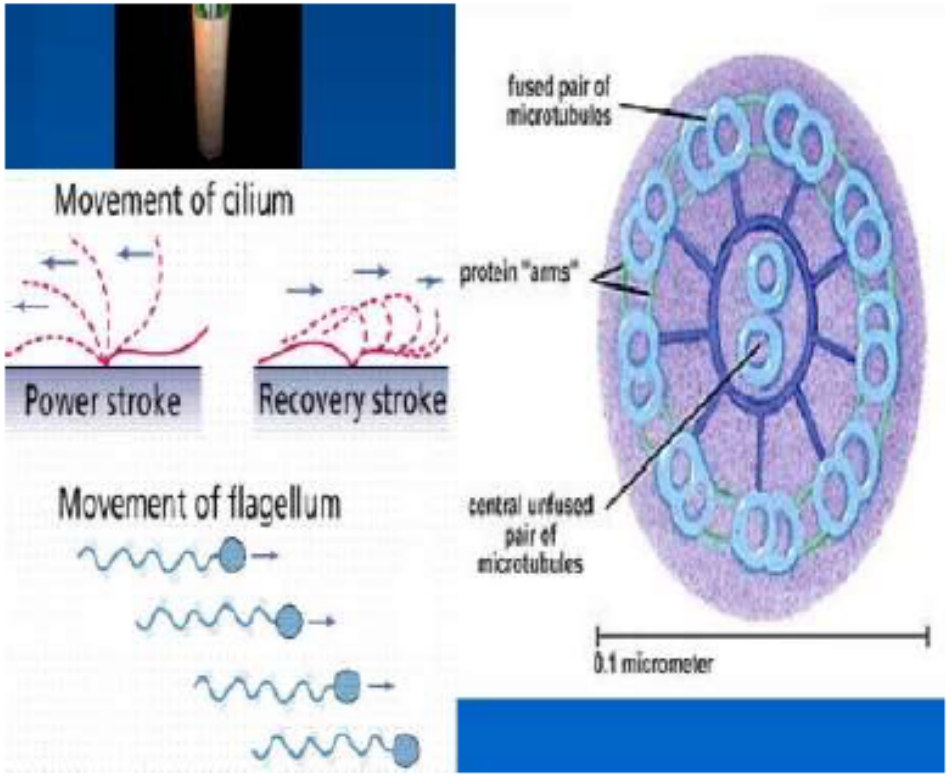


Cilia and flagella

1) **Cilia and flagella** are hair-like organelles that extend from the surface of cells.
2) **Cilia and flagella** are made up of microtubules.
3) Main function is cell motility/ helps in cell movement, steady movement of fluid along cell's surface

Cilia are large in numbers, and are found in cell surfaces of respiratory tract that help sweep foreign particles trapped in mucus away from lungs. Uterine lining also have cilia that sweeps oocytes towards uterus.

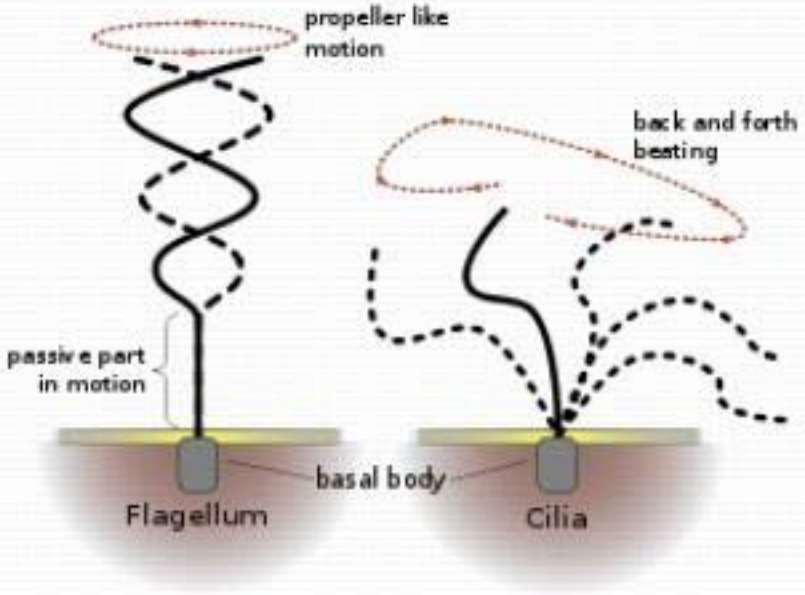
Flagella is found in sperm cell's tail which propels the sperm towards its possible union with an oocyte



Flagella & Cilia

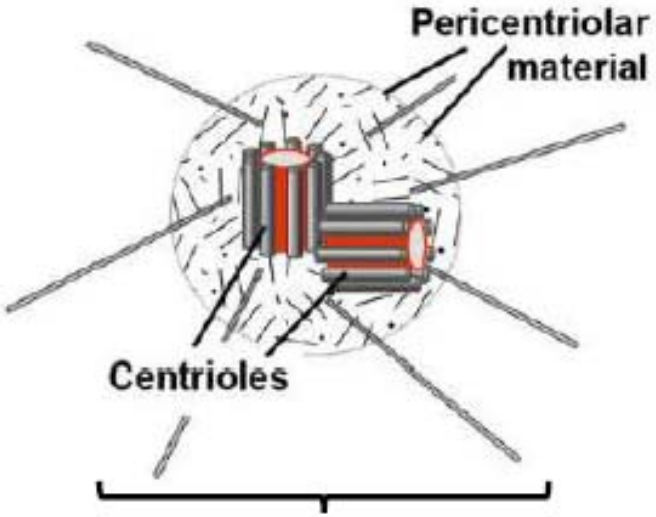
Whip-like appendages of cells that are the main source of movement in Eukaryotic cells.

- Flagella
  - 1-2 Long appendages
  - Tail like appendage.
- Cilia
  - Several short appendages.
  - Usually lines the cell.

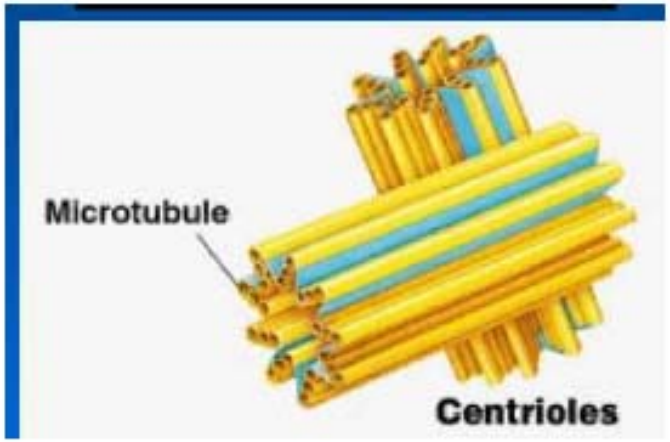


Centrosomes and centrioles

- In many cells, microtubules grow out from a **centrosome** near the nucleus
- The centrosome is a "microtubule-organizing center"
- In animal cells, the centrosome has a pair of **centrioles**, each with nine triplets of microtubules arranged in a ring



- **Structure: composed of nine sets of triplet microtubules arranged in a ring**
  - **Exist in pairs**
- **Function: centrioles play a major role in cell division (mitosis)**



Quiz: Cell Organelles and Their Functions

1. This organelle functions in cellular respiration:

- lysosome
- endoplasmic reticulum
- mitochondrion
- golgi apparatus

2. The organelle functions to package and deliver proteins:

- lysosome
- endoplasmic reticulum
- mitochondrion
- golgi apparatus

3. Cell organelles are located within the ____ of the cell.

- nucleus
- cytoplasm
- cell membrane
- lysosomes

4. The endoplasmic reticulum functions to:

- transport materials
- destroy old cell parts
- make ribosomes
- package proteins

5. Genetic material is contained within the ___ of the cell.

- ribosomes
- cytoplasm
- nucleus
- nucleolus

6. This organelle is responsible for destroying worn-out cell parts:

- lysosomes
- mitochondrion
- golgi apparatus
- ribosomes

7. The _____ controls what enters and leaves the cell.

- mitochondrion
- golgi apparatus
- nucleus
- cell membrane

8. The rough endoplasmic reticulum has ____ located on it.

- lysosomes
- cytosol
- ribosomes
- proteins

9. Located within the nucleus, it is responsible for producing ribosomes:

- centrosome
- nucleolus
- lysosome
- endoplasmic reticulum

10. Which structure is directly responsible for the formation of proteins within the cell.

- lysosomes
- vacuoles
- centrioles
- ribosomes