CATHOLIC JUNIOR COLLEGE
9744 H2 Biology

CORE IDEA: 1] THE CELL AND BIOMOLECULES OF LIFE

1.1 ORGANELLES AND CELLULAR STRUCTURES

Narrative: *Cellular structures provide the means to drive cellular processes*
Knowing how cellular structures facilitate specific cellular processes is fundamental to explaining how life 'works'. The cell theory states that the cell is the smallest and most basic unit of life and that cells grow only from existing cells. Understanding the role of cellular organelles (such as nucleus, ribosome, chloroplast and mitochondrion) and cellular structures (for example, the cytoskeleton) is crucial to understanding how organisms and life at large work. One key concept often explored in this chapter is "how are the structures of the organelles adapted for their functions?"

There are significant differences between cells of prokaryotes and eukaryotes. Using bacteria as a model, the nucleoid is not enclosed by any membrane. Plasmid may be present as extra-chromosomal DNA. Membrane-bound organelles, such as mitochondria and endoplasmic reticulum, are absent. Prokaryotic ribosomes are different from eukaryotic ribosomes. Some bacterial cells have cell walls that comprise peptidoglycan rather than cellulose. Within the eukarya domain, the cell model of plants is also different from that of animals. Unlike unicellular organisms which merely undergo cellular division, cells of multicellular organisms undergo both division and differentiation to allow them to carry out their specific functions.

Guiding Questions:
- Why is a cell the basic unit of life and how does it promote continuity of life?
- How is the basic unit crucial in understanding what constitutes life?
- What are the differences between cells of prokaryotes and eukaryotes, between cells of plants and animals, and between cells of unicellular and multicellular organisms?
- In what ways do viruses not fit the cell model?

LEARNING OUTCOMES

Candidates should be able to:

Subtopic	Learning Outcomes	Pg.
Cell Theory	**(a)** Outline the cell theory with the understanding that cells are the smallest unit of life, all cells come from pre-existing cells; and living organisms are composed of cells.	3
Eukaryotes	**(b)** Interpret and recognise drawings, photomicrographs and electronmicrographs of the following membrane systems and organelles: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus. **(c)** Outline the functions of the membrane systems and organelles listed in (b).	3-22
Prokaryotes (Bacteria)	**(d)** Describe the structure of a typical bacterial cell (small and unicellular, peptidoglycan cell wall, circular DNA, 70S ribosomes and lack of membrane-bound organelles).	23-27
Viruses	**(e)** Describe the structural components of viruses, including enveloped viruses and bacteriophages, and interpret drawings and photographs of them. **(f)** Discuss how viruses challenge the cell theory and concepts of what is considered living. [not in student lecture notes, but discussed in tutorials]	28-32 33

REFERENCES
1. Campbell, Neil A and Reece, J B (2015) Biology: A Global Approach (10[Th] edition) (Pearson global edition)
2. Campbell, Neil A and Reece, J B (2011) *Biology* (Ninth edition) (Addison Wesley-Benjamin Cummings, www.aw-bc.com)
3. Campbell, Neil A and Reece, J B (2005) *Biology: Concepts and Connections* (Fourth edition) (Benjamin Cummings)
4. Taylor, D J, Green, N P O, Stout, G W and Soper R (1997) *Biological Science 1* (Third edition) (CUP, www.cambridge.org) ISBN 0521561787
5. *Longman A-Level Course in Biology (Core Syllabus)* by Hoh Y. K.
6. *Biology of Microorganisms* (Seventh Edition) by Brock Madigan Martinko Parker

CONTENT PAGE

1] CELL THEORY

Cell Theory	**LO (a)** Outline the **cell theory** with the understanding that cells are the smallest unit of life, all cells come from pre-existing cells; and living organisms are composed of cells.

Cell Theory arose in the mid-nineteenth century as a result of work by three German biologists, Schleiden, Schwann and later, Virchow.

The Cell Theory states that:

i) The cell is the **smallest**, **most basic** unit of life, in terms of structural, functional and organisation of an organism.
ii) All living organisms are **composed of cells**. Organism could be unicellular or multicellular.
iii) All cells **arise from pre-existing cells** by cell division, through mitosis and meiosis in eukaryotic cells and binary fission in prokaryotes.

2] EUKARYOTES

EUKARYOTES are organisms made of cells that **have a true, membrane bound nucleus**. They **also possess membrane bound organelles**. Examples of eukaryotic organisms are **animals** (Fig. 3), **plants** (Fig. 4), fungi and protoctists.

A typical eukaryotic cell consists of the following:

(a) **Cell surface membrane**
This defines the boundary of a cell and retains its contents.

(b) **Nucleus**
This contains the genetic material that directs cellular activities.

(c) **Cytoplasm**
This consists of the following:

- <u>Cytosol</u>
  This is the **aqueous solution** of ions and organic compounds (e.g. sugars, amino acids and proteins).

- <u>Organelles</u>
  These include the organic cellular structures, usually enveloped by a membrane, such as the ribosome, endoplasmic reticulum, Golgi body, lysosome, mitochondrion, vacuole and centriole.

- <u>Cytoskeleton</u>
  This consists of a network of microtubules, intermediate filaments and microfilaments made of protein.

FIG. 3: ANIMAL CELL

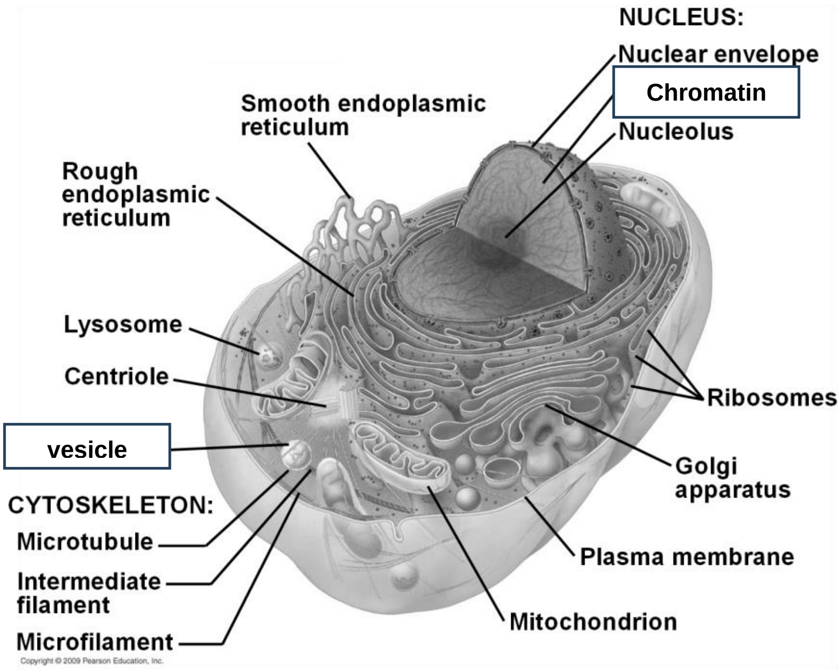


Fig. 3a 3-dimensional model of an Animal Cell

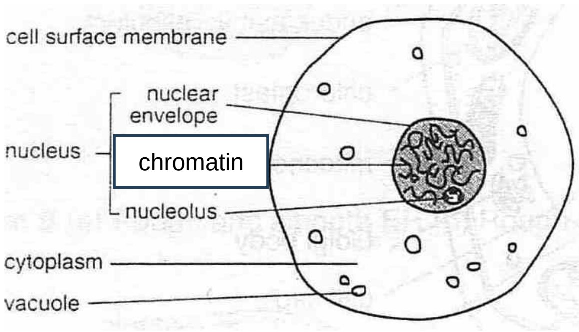


Fig.3b An illustration of an Animal Cell

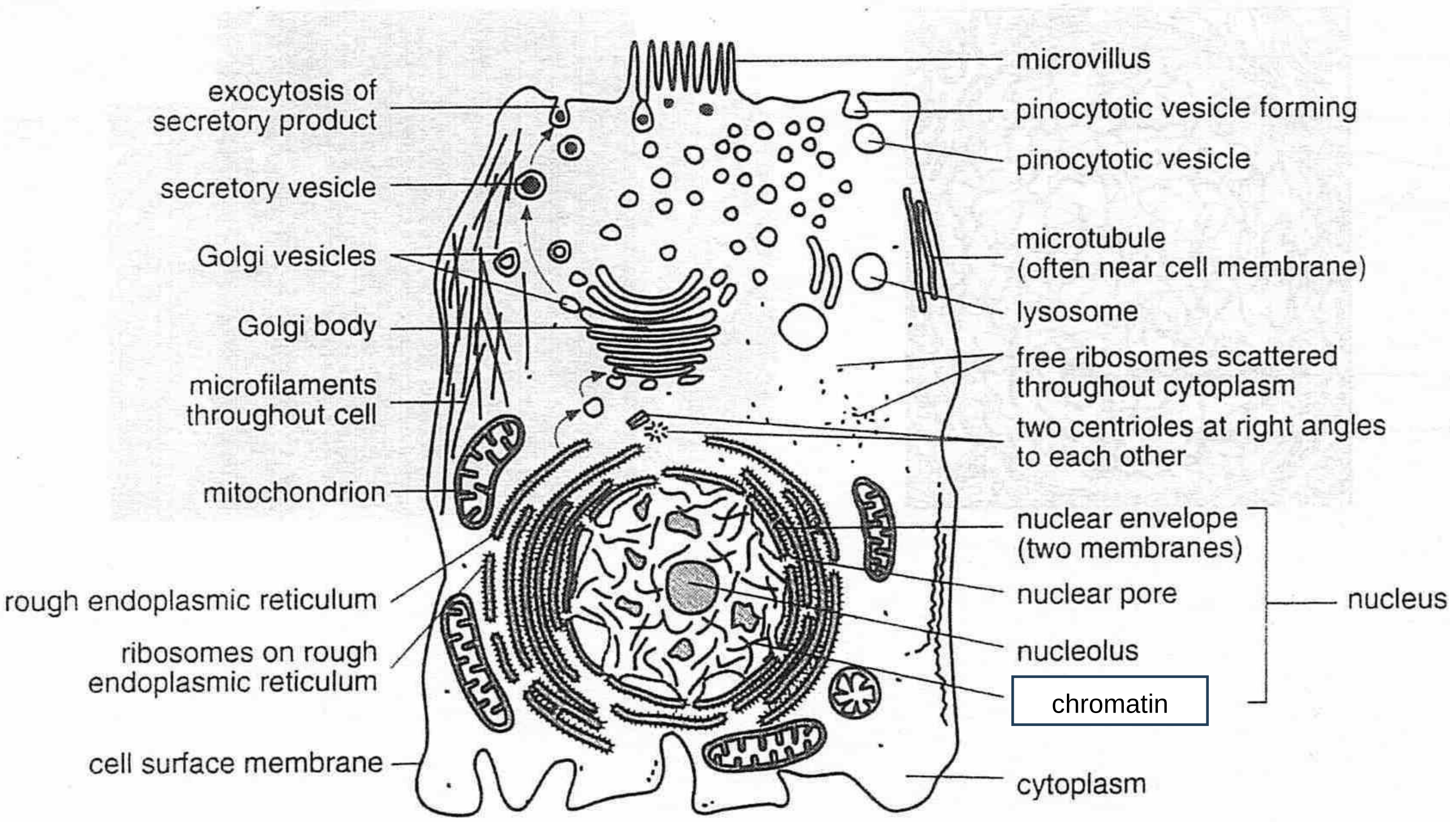


Fig. 3c An illustration of a generalised animal cell as seen with the **Electron Microscope**

FIG. 4: PLANT CELL

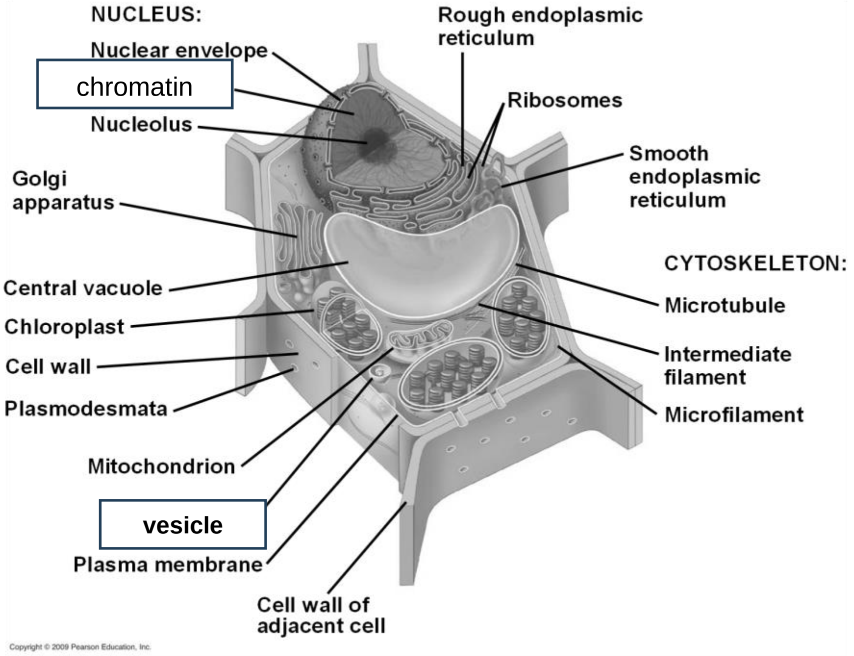


Fig. 4a 3-dimensional model of a Plant cell

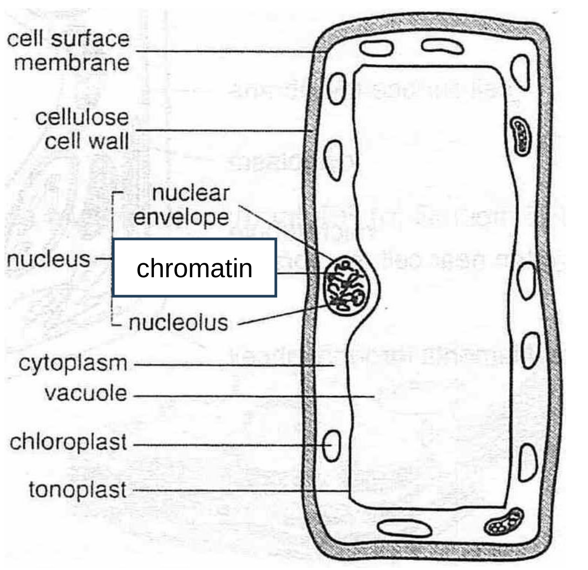


Fig.4b An illustration of a plant cell as seen under a **Light Microscope**

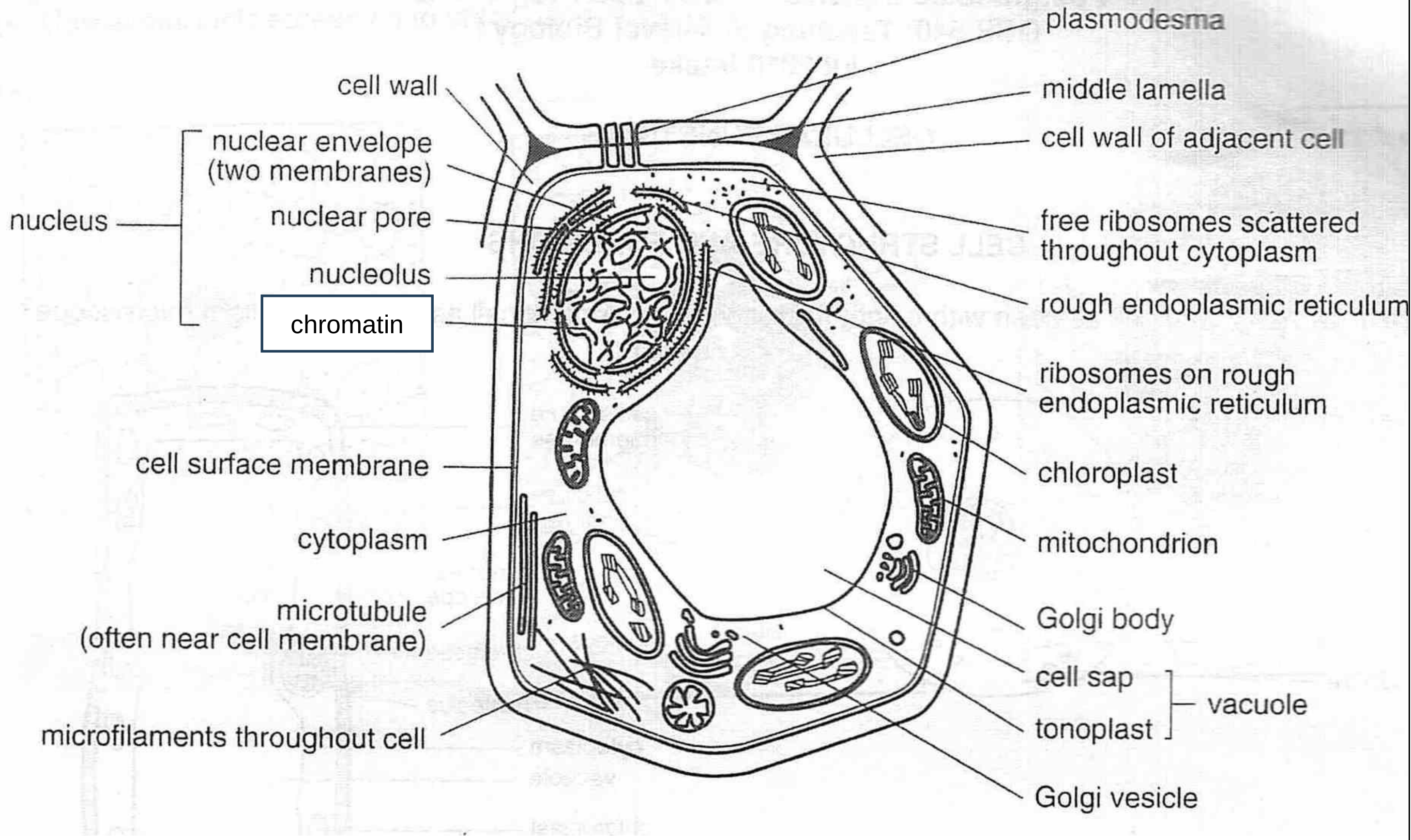


Fig. 4c An illustration of a generalised plant cell as seen with the **Electron Microscope**

COMPARISON BETWEEN PLANT CELL AND ANIMAL CELL:

Basis of Comparison (Features)	Plant cell	Animal cell
Cell wall	Tough, slightly elastic cellulose cell wall present (in addition to the cell membrane)	Cell wall absent – only a membrane surrounds the cell
Pits and plasmodesmata	Pits and plasmodesmata present in the cell wall	No cell wall and therefore no pits or plasmodesmata
Plastids	Plastids, e.g. chloroplasts and leucoplasts, present in large numbers	Plastids absent
Vacuoles	Mature cells normally have a large single, central vacuole filled with cell sap	Vacuoles, e.g. contractile vacuoles, if present, are small and scattered throughout the cell
Tonoplast	Tonoplast present around vacuole	Tonoplast absent
Cytoplasm	Cytoplasm normally confined to a thin layer at the edge of the cell	Cytoplasm present throughout the cell
Nucleus	Nucleus at edge of the cell	Nucleus anywhere in the cell but often central
Lysosomes	Lysosomes are not present (vacuoles carry out similar function)	Lysosomes almost always present
Cilia and flagella	Cilia and flagella absent in higher plants	Cilia or flagella often present
Storage	Starch grains used for storage	Glycogen granules used for storage
Cell division	Only some cells are capable of division	Almost all cells are capable of division
Secretions	Few secretions are produced	A wide variety of secretions are produced
Centrioles	Centrioles absent in higher plants	Centrioles present

2] EUKARYOTES

Eukaryotes	**LO (b) Interpret and recognise drawings, photomicrographs and electronmicrographs of the following membrane systems and organelles**: rough and smooth endoplasmic reticulum, Golgi body, mitochondria, ribosomes, lysosomes, chloroplasts, cell surface membrane, nuclear envelope, centrioles, nucleus and nucleolus. **LO (c)** Outline the **functions** of the **membrane systems and organelles** listed in LO (b).

CONCEPT MAP FOR ORGANELLES

- Organelles
  - Non-membrane bound
    - ribosome
    - centrioles
  - Membrane bound
    - Single membrane
      - Rough Endoplasmic Reticulum (RER)
      - Smooth Endoplasmic Reticulum (SER)
      - Golgi body
      - Lysosome
    - Double membrane
      - Nucleus (plural: nuclei)
      - Chloroplast
      - Mitochondrion (plural: mitochondria)

2.1] CELL SURFACE MEMBRANE (Fig. 6)

A. STRUCTURE

- The cell surface membrane is a **single membrane** found at the **periphery of the cell**; it is named cell surface membrane to differentiate from other cell membranes found *inside* the cell.
- The cell surface membrane is made of biomolecules such as **phospholipids, cholesterol, glycolipids, proteins and glycoproteins**.
- The cell surface membrane comprises of **two layers of phospholipids** called the **phospholipid bilayer**. The **hydrophobic "tails" facing away from the aqueous medium** ("*facing inwards*") **and the hydrophilic "heads" facing towards the aqueous medium** ("*facing outwards*").

B. FUNCTION

- The cell surface membrane **regulates the movement of molecules into and out of the cell**, a trait called **selective permeability**.

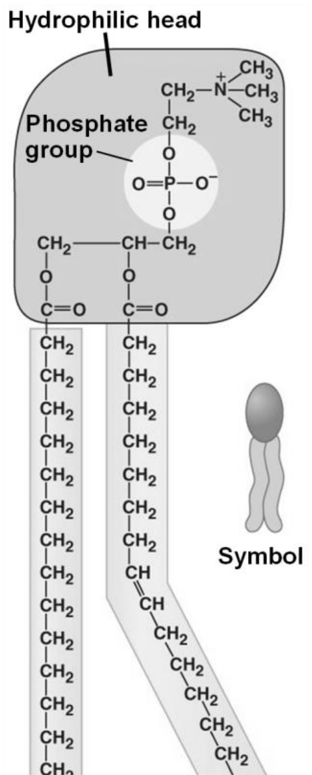


Fig.5 Structure of phospholipid

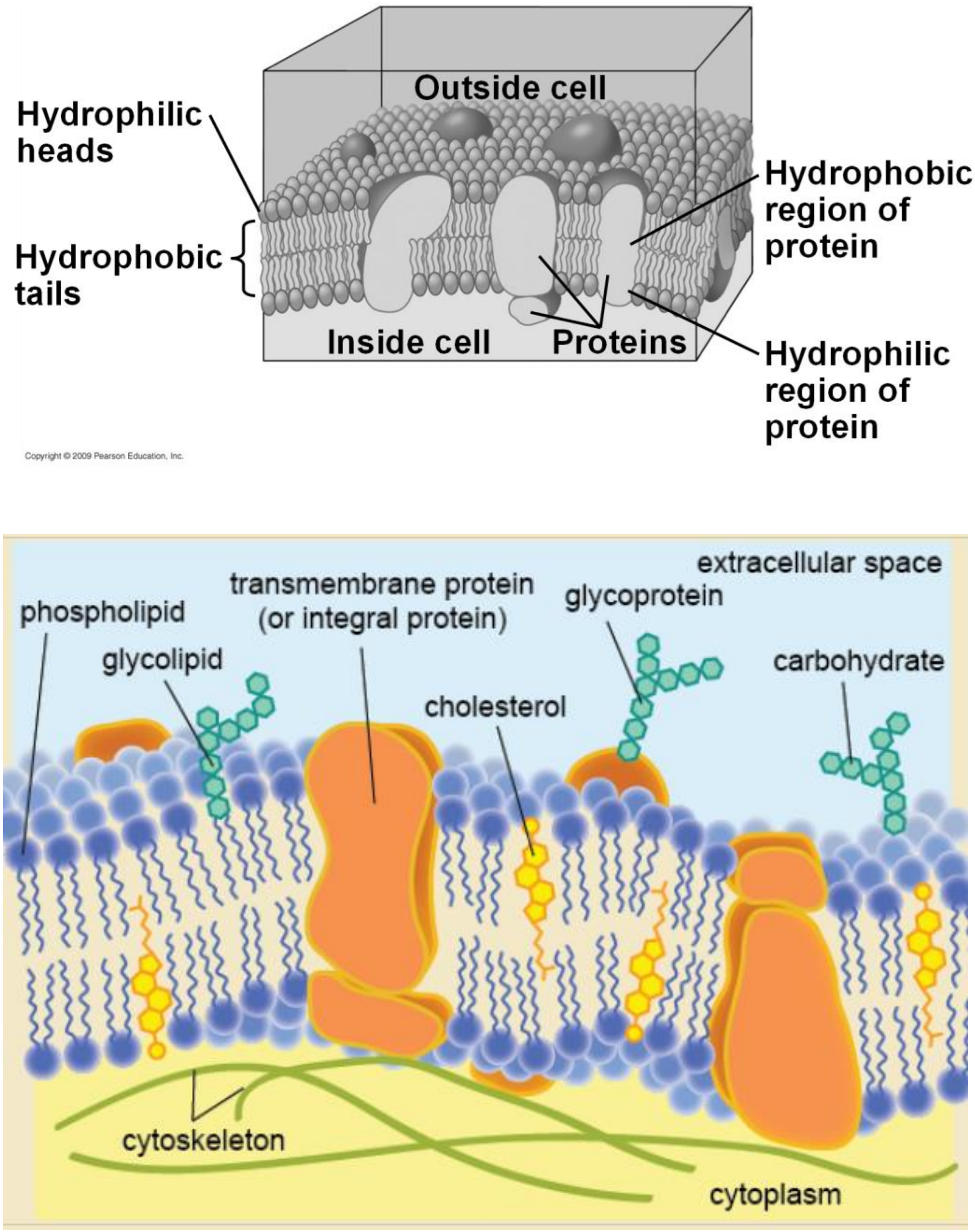


Fig.6 Structure of cell surface membrane

NON-MEMBRANE BOUND ORGANELLES:

2.2] RIBOSOMES (Fig. 7)

A. STRUCTURE

- Ribosomes are organelles made of **ribosomal RNA** and **protein**.
- They are about **20-30 nm** in diameter.
- Each ribosome consists of **one small subunit** made of one molecule of rRNA with 21 molecules of proteins and **one large subunit** made of two molecules of rRNA with 34 molecules of proteins.
- There are two types of ribosomes: **70S**, which are found in **prokaryotes**, **chloroplasts** and **mitochondria**; and **80S**, which are found in **eukaryotes** as **free ribosomes in the cytoplasm** and **attached to the rough endoplasmic reticulum**. (S = Svedberg unit or Sedimentation coefficient)
    - Prokaryotes - 70S ribosome is made up of a 30S small ribosomal subunit and a 50S large ribosomal subunit.
    - Eukaryotes - 80S ribosome is made up of 40S small ribosomal subunit and a 60S large ribosomal subunit.
- Each ribosome has **three binding sites** for **tRNA** (transfer RNA):
    - i **A site** (aminoacyl-tRNA site): holds the tRNA carrying the next amino acid to be added to the chain.
    - ii **P site** (peptidyl-tRNA site): holds the tRNA carrying the growing polypeptide chain.
    - iii **E site** (exit site): discharged tRNAs leave the ribosome from the E site.

B. FUNCTION

1. The main function of ribosomes is to serve as **site of protein synthesis**.
2. Ribosomes **bound to endoplasmic reticulum** generally **make proteins** that are destined either for **inclusion into membranes**, for **packaging within certain organelles such as lysosomes** or for **export from the cell**.
3. Ribosomes **lying free in cytoplasm** are sites of synthesis of proteins retained **within the cell**, i.e. function within cytosol, enzymes that catalyses metabolic processes localized within cytosol.

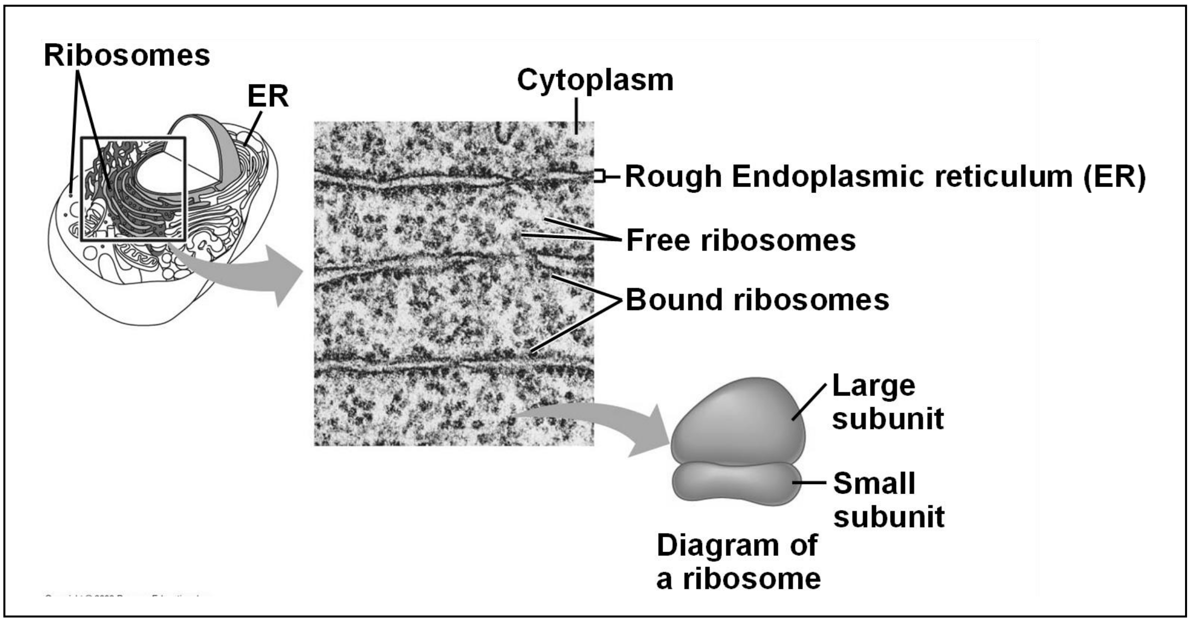


Fig.7a Structure of Free and Bound Ribosomes

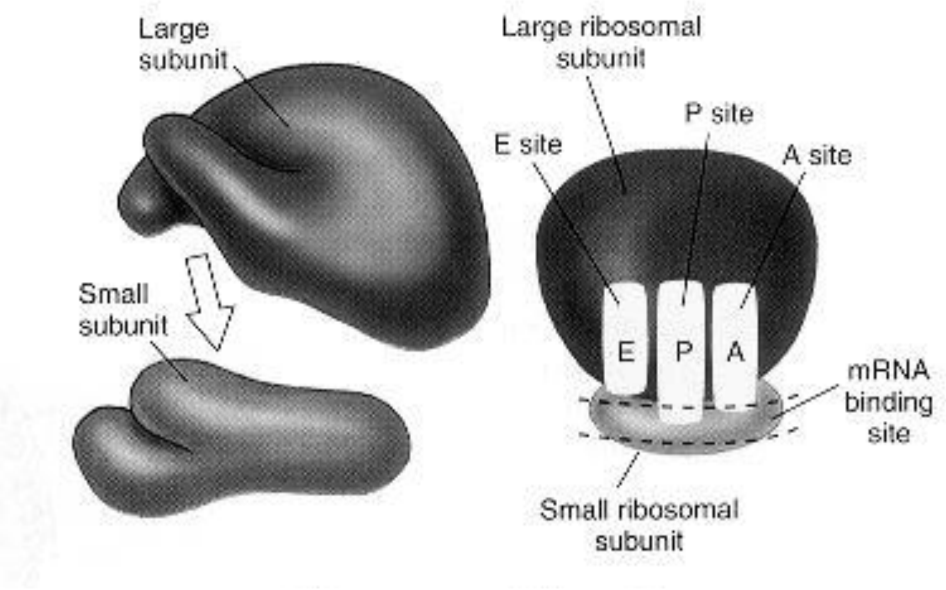


Fig. 7b Ribosome subunits with its corresponding binding sites

2.3] CENTRIOLES (Fig. 8)

A. STRUCTURE

- They measure around 0.2 μm in diameter and 0.3 to 0.5 nm in length
- From the transverse section of the centriole as seen under the TEM (Transmission Electron Microscope), **9 triplets of microtubules** are fused together to give a rod-like structure.
- Each centriole is positioned at **90° to each other** and are situated next to nucleus
- Only found in animal cells

B. FUNCTION

1. Organise spindle fibres during cell division.
2. Anchorage for cilia and flagella.

(a) (b) (c)

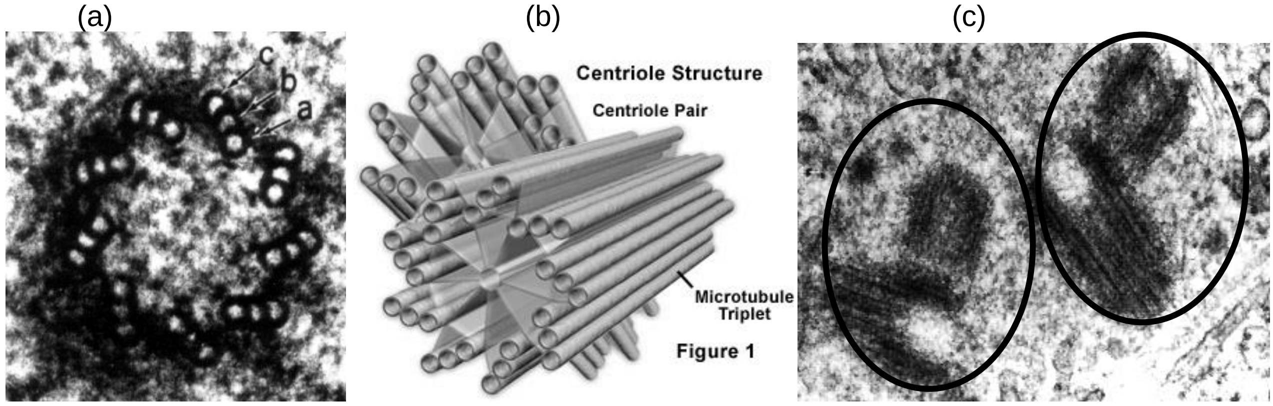


Fig. 8 Structure of Centriole, (a) single (b) a pair (c) two pairs

SINGLE MEMBRANE BOUND ORGANELLES:

2.4] ENDOPLASMIC RETICULUM (ER) (Fig. 9 and Fig. 10)

- It consists of complex **membrane-bound sacs** called **cisternae** (plural; singular: cisterna).
- There are 2 types of ER of which each has a different role in synthesis and packaging. They are namely, the **rough endoplasmic reticulum (rER)** and the **smooth endoplasmic reticulum (sER)**.

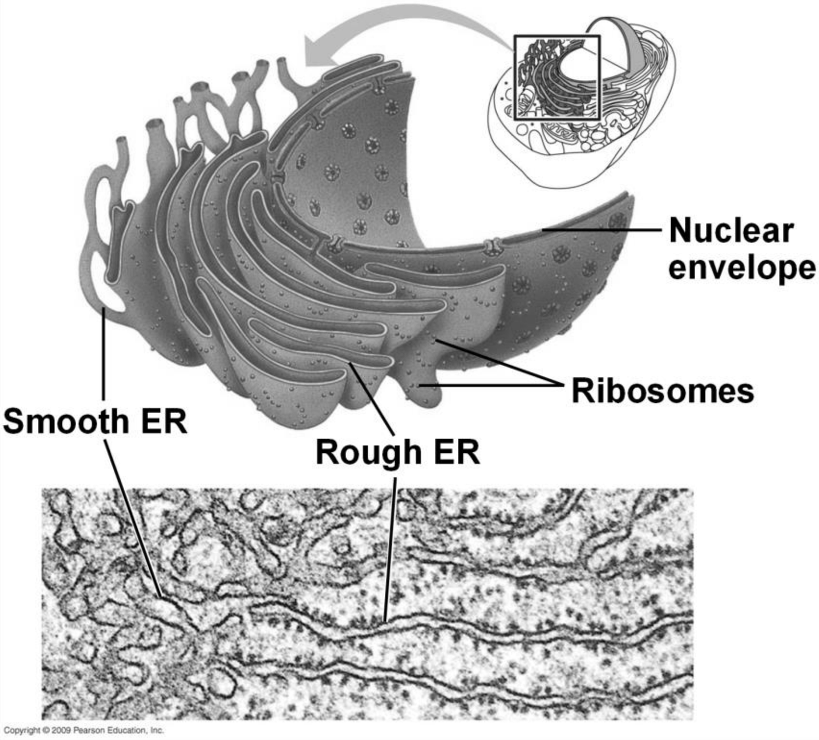
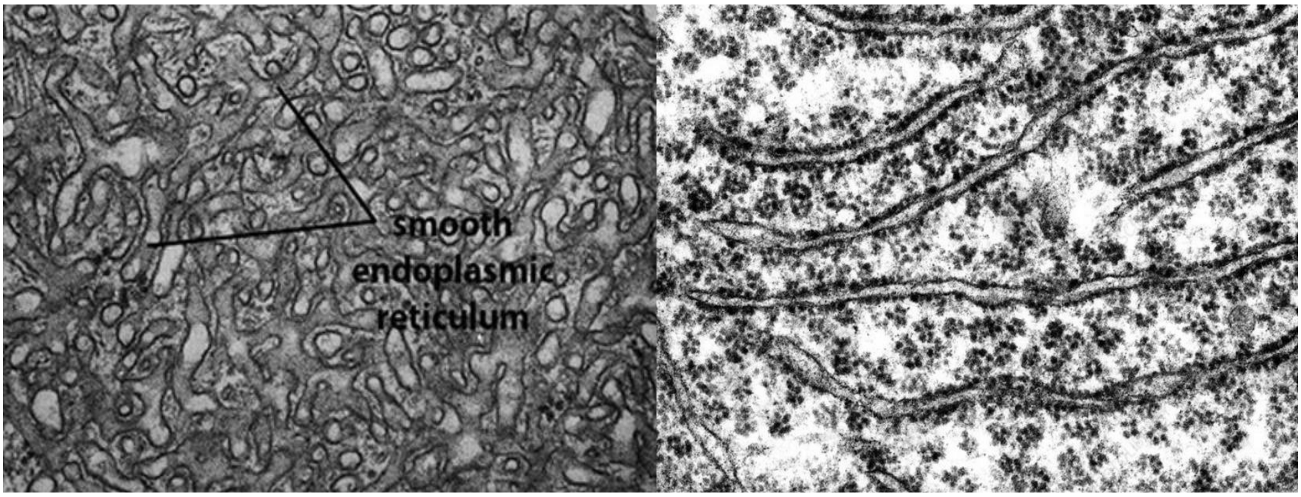


Fig.9 Structure of Endoplasmic reticulum: Rough ER and Smooth ER



Smooth ER

Rough ER

Fig.10 Electron micrograph of Rough ER and smooth ER

2.4.1] ROUGH ENDOPLASMIC RETICULUM (rER)

A. STRUCTURE
- Cisternae are **flattened** and **interconnected** with each other (Fig. 14) and are **continuous with the outer membrane of the nuclear envelope**.
- Ribosomes are found on the surface, which are sites of protein synthesis; these many ribosomes give the rough / **granular appearance** on the rER (Fig. 10)
- It can be broken into small pieces and resealed into vesicles known as microsomes during the homogenization procedure.

B. FUNCTION
- Ribosomes are associated with the rough ER for **protein synthesis**.
- Enzymes in ER membrane modifies the polypeptides, attaches carbohydrates to proteins, forming **glycoproteins**.
- Rough ER **increases surface area** of the intra-cellular membranes for **biochemical reactions**.
- Rough ER forms a separate compartment allowing metabolic reactions to be localized.
- Rough ER stores secretions, e.g. hormones.
- Rough ER serves as an **intracellular transport network** between various parts of the cytoplasm and between cytoplasm and nucleus. For example, **rough endoplasmic reticulum transports proteins** to other parts of the cell by **transport vesicles** which are pinched off from the membrane of the endoplasmic reticulum.

2.4.2] SMOOTH ENDOPLASMIC RETICULUM (SER)

A. STRUCTURE
- The smooth E.R. lacks ribosomes.
- It consists of **tubular** cisternae (Fig 11).
- It has a different set of membrane-bound proteins from the rough endoplasmic reticulum.

B. FUNCTION
1. **Lipid and steroid synthesis and transport**. (e.g. phospholipids and steroid hormones)
2. **Detoxification of drugs and poisons**, e.g. detoxification of carcinogens in the liver.
3. Secretion of chloride ions (Cl^-) in the stomach.
4. Storage and release of calcium ions (Ca^{2+}) especially in the sarcoplasmic reticulum of muscles.

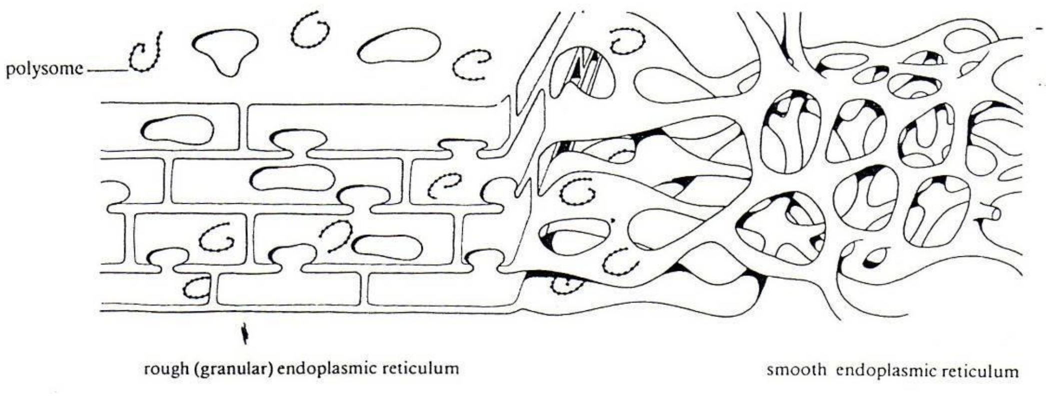


Fig.11 Flattened cisternae of RER and Tubular cisternae of SER

2.5] GOLGI BODY / APPARATUS (Fig. 12)

A. STRUCTURE

- It consists of **flattened saucer-like** membrane-bound stacks called **cisternae** and a system of associated vesicles called **Golgi vesicles**.
- This is seen as a **single large stack** in animal cells and in separate stacks in plant cells.
- It consists of a **cis face** and a **trans face** (Fig. 12).
- At the **cis face** or the outer convex face, new cisternae are constantly formed by the fusion of **transport vesicles** which budded from the rough ER and smooth ER.
- At the **trans face** or the inner concave face, the Golgi body breaks up to form **vesicles** such as lysosomes or **transport vesicles**.

B. FUNCTION

1. **Chemical modification of proteins and lipids**
   Enzymes of the Golgi body attach **short carbohydrate chains** to **proteins** and **lipids** to form **glycoproteins** and **glycolipids** respectively.

2. **Further Chemical modification** of **existing glycoproteins** and **glycolipids**
   Note: Carbohydrates are first added to proteins in the rough ER usually during the process of polypeptide synthesis. The carbohydrate on the resulting glycoprotein is then further modified as it passes through the ER and the Golgi body.

   Enzymes of the Golgi body may also perform further modification, such as **cleaving / trimming** the **carbohydrate chains** or **modifying** the **sugar** on the carbohydrate chain.

3. **Sorting and Packaging**
   The various molecules in the Golgi body are then **sorted and packaged into vesicles before distributed** to **other parts of the cell** or **secreted out of the cell**.
   a. **Hydrolytic enzymes** of the **lysosome** will be **sorted** and **packaged together** to eventually form the **membrane-bound digestive vesicle.**
   b. **Secretory proteins will be sorted and packaged into secretory vesicles, to be secreted out of the cell.**
   c. **Membrane proteins** will be **sorted and embedded into the membrane of the secretory vesicle** which will be transported and fused with the cell surface membrane.
   d. Proteins meant for the other organelles are sorted and packaged into vesicles, to be transported to the target organelles.

4. In **plant cells**, **non-cellulose polysaccharide** of the **cell wall** (i.e. **pectin**) are also synthesised.

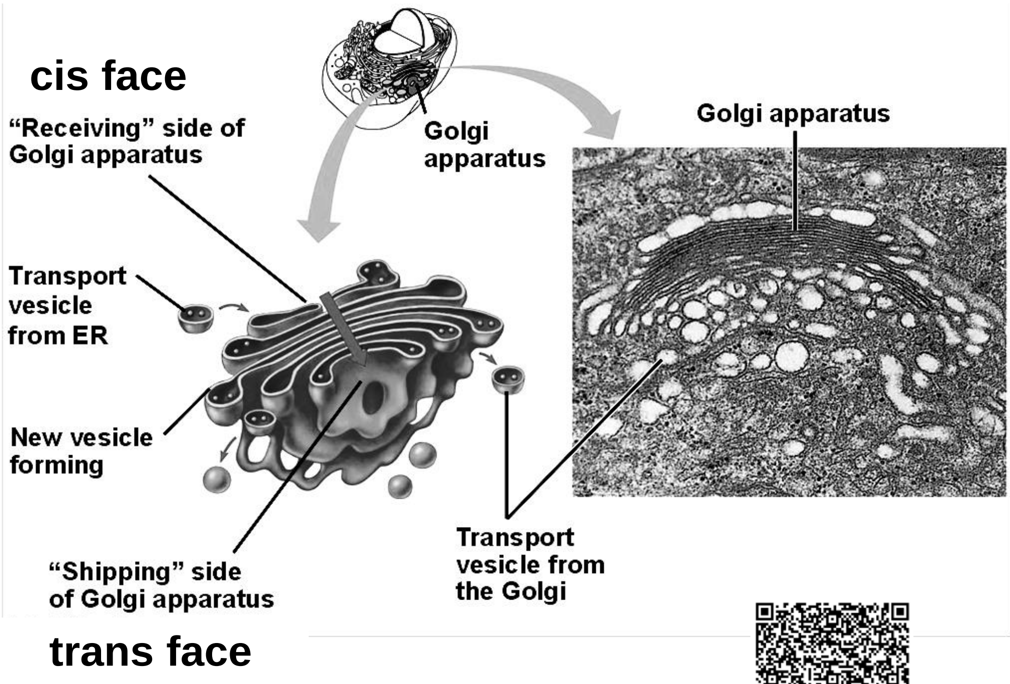


Fig. 12 Structure of Golgi body

2.6] LYSOSOMES

A. STRUCTURE

- **Spherical sacs** of 0.2 - 0.5 µm in diameter.
- It contains **hydrolytic enzymes** such as proteases and lipases.
- It serves as a **storage vesicle** to keep the degradative enzymes apart from the rest of the cell, hence preventing them from destroying the cell.
- Its contents are **acidic**.
- There are 2 types of lysosomes: **primary lysosome** and **secondary lysosome**:
  i. **Primary Lysosomes**
    - Processed enzymes are contained in the Golgi vesicles which later bud off.
    - These enzymes are first synthesized on the rough ER and later transported to Golgi body.

  ii. **Secondary Lysosomes**
    - Primary lysosomes become secondary lysosomes after fusion with certain vacuoles.

B. FUNCTION

1. **Digestion** of materials (Fig.13a).
   Enables the cell to breakdown the particles taken via phagocytosis.
   - Primary lysosomes fuse with the endocytotic vesicles so that the digestive enzymes could break down the contents.
   - The useful products are passed into the cytosol while the residue is discharged by exocytosis.

2. **Autolysis**
   Self destruction of the cell by the release of the lysosomal contents within the cell.

3. **Autophagy** (Fig.13b)
   Destruction of worn out organelles by fusing the organelles with primary lysosome to form secondary lysosome.

DOUBLE MEMBRANE BOUND ORGANELLES

2.7] NUCLEUS (singular; plural: nuclei)

A. STRUCTURE OF NUCLEUS

- It is found in all eukaryotic cells except in mature red blood cells in mammals and in sieve tubes in plants.
- It is usually spherical or ovoid (Fig. 14) and averages about 2-10 µm in diameter. It is the **largest** and most conspicuous organelle within eukaryotic cells and can be easily observed under a light microscope.
- It has a **double membrane**, called the **nuclear envelope**.
  - i. Note: Each of the membranes of the double membrane is a bilayer.
  - ii. The double membrane is **two bilayers with a gap in between them**.

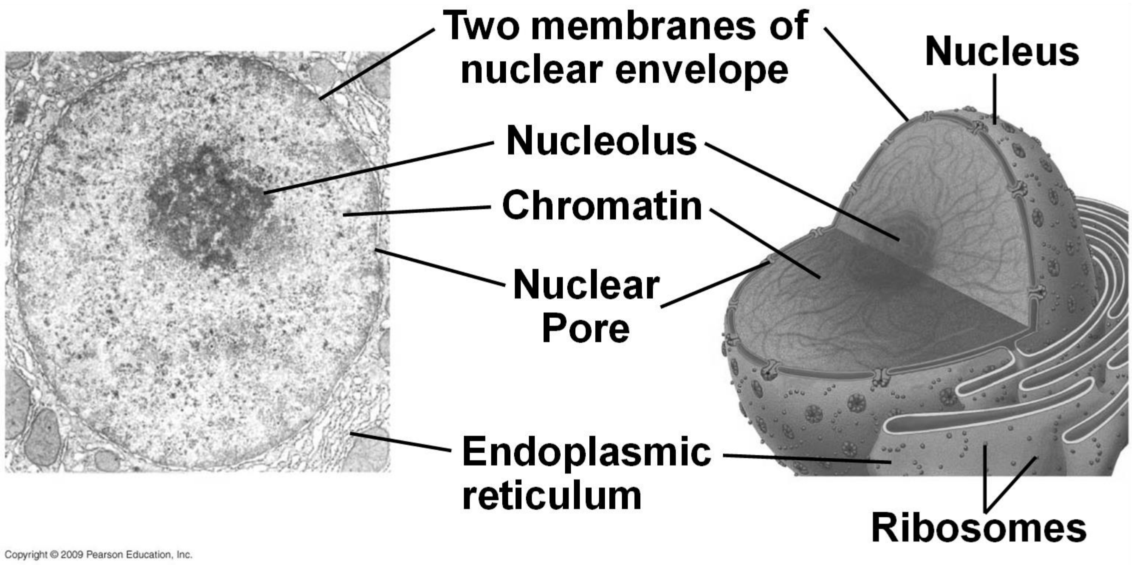


Fig. 14 Structure of a nucleus and its associated structures and membranes

B. FUNCTION

1. It contains DNA, which is the genetic material of the cell and **controls all cellular activities** including **cell division** and **protein synthesis**.

2.7a] DNA in the nucleus:

- The nucleus contains most of a eukaryotic cell's DNA and is organized along with proteins, known as histones into long threads called **chromatin**.
- Two different levels of packing of DNA molecules: **Heterochromatin** (more condensed, appears darker) and **Euchromatin** (less condensed, usually not stained; see Fig. 15).
- Chromatin do not stain intensely and are too dispersed or thin to be observed under a light microscope. During nuclear division, chromatin **condenses** into a more tightly coiled thicker threads called chromosomes and hence stain more intensely.

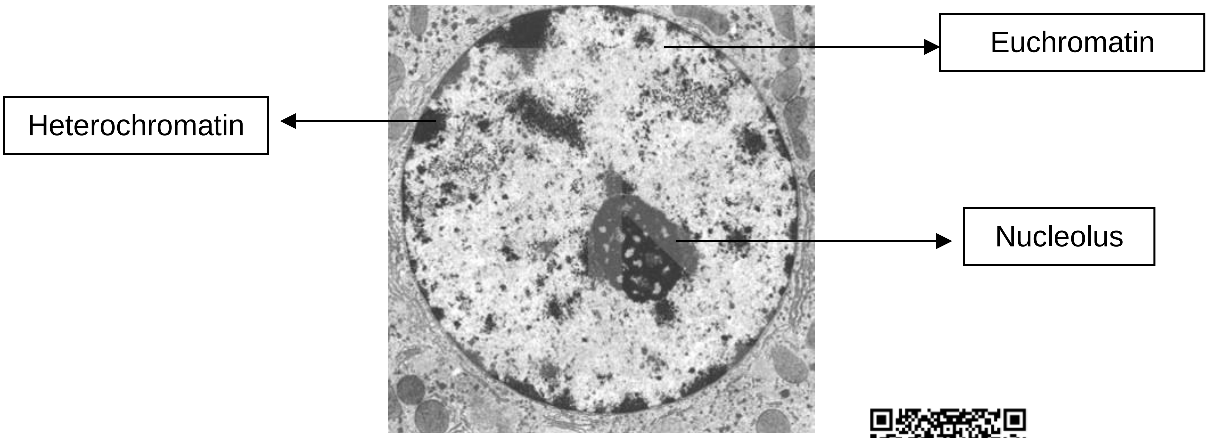


Fig. 15 Structure of a nucleus

2.7b] NUCLEOLUS (plural: Nucleoli)

A. STRUCTURE OF NUCLEOLUS

- It is a **large and dense** region inside the nucleus. It is **not an organelle** but simply a region in the nucleus. [Note: Do not confuse with heterochromatin!]
- It consists of a fibrous part and a granular part.
- The fibrous part contains large loops of DNA from several chromosomes containing genes from which **rRNA** (ribosomal RNA) is transcribed to become part of **ribosomes**. (Fig. 16)
- The granular part contains transcribed rRNA fragments and synthesized ribosome subunits which then migrate to the cytoplasm to assemble into ribosomes.
- Most nuclei have two nucleoli, however in most diagrams only one is illustrated.

B. FUNCTION OF NUCLEOLUS

- The function of nucleolus is to direct protein synthesis by synthesizing and controlling the **synthesis of ribosomes**.

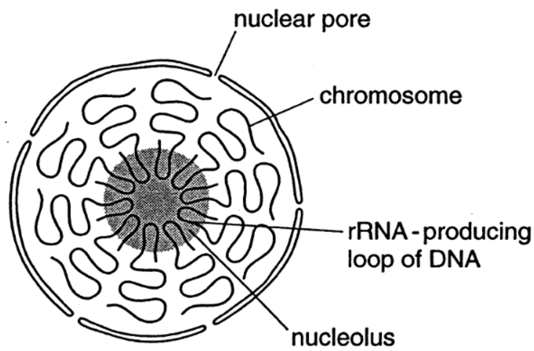


Fig.16 Relationship between nucleolus and rRNA

2.7c] NUCLEAR ENVELOPE

A. STRUCTURE OF NUCLEAR ENVELOPE

- It is a **double membrane** including an outer membrane which is continuous with the rough endoplasmic reticulum.
- The double membrane is perforated by **nuclear pores** (about 50 nm in diameter). Each pore consists of eight pore proteins and a 'plug' protein (Fig.17).

B. FUNCTION OF NUCLEAR ENVELOPE

- The nuclear pores provides a **channel** through which molecules (e.g. mRNA) can move between the nucleus and the cytoplasm.
- The exchange of materials through each pore is a carefully controlled and highly selective process.
- Hence nuclear envelope helps to maintain a chemical environment within the nucleus different from that in the surrounding cytoplasm.
- It disintegrates during nuclear division; i.e. mitosis and meiosis.

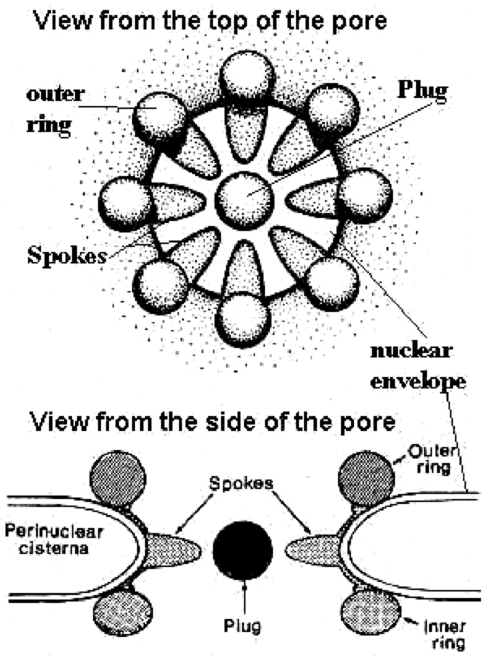


Fig.17 Structure of a nuclear pore

2.7d] Nucleoplasm

- Similar to how the cytoplasm which fills up the cell outside the nucleus, this is a **semi-fluid matrix** that fills up the nucleus.

  Note: A matrix refers to a fluid-filled space in which structures are embedded in.

2.8] MITOCHONDRION (plural: Mitochondria)

A. STRUCTURE

- The mitochondrion is an organelle that is responsible for the **synthesis of energy (ATP)** through the metabolism of glucose and other metabolites. (Fig. 18)
- It is 1.5 – 10 µm in length and 0.25 - 1.00 µm in width.
- It has a double membrane bound structure with an **outer membrane** that is **smooth,** and an **inner membrane** that is folded into finger-like projections called **cristae** (plural; singular: crista).
- **The inner membrane is folded** to **increase the surface area** for proteins and enzymes involved in the Electron transport chain (ETC) and oxidative phosphorylation processes in **cellular respiration**.

  E.g. **Stalk particles** are present on the **inner membrane**. Each particle contains a head piece, stalk and base. The head piece contains **ATP** (Adenosine triphosphate) **synthase** for ATP synthesis.
- The **mitochondrial matrix** contains **circular mitochondrial DNA**, **ribosomes (70S)**, **RNA** and **enzymes involved in the Krebs cycle of respiration**.

B. FUNCTION

1. Site for **catabolic respiratory activity** within the cell, where **ATP is synthesized**. **Energy in the form of ATP** is made available for cellular functions. This is the primary function of the mitochondria.
2. **Lipid metabolism** for cellular respiration. Fatty acids are broken down to acetyl CoA in the matrix and on the inner membrane of the mitochondrion.
3. A site for **lipid synthesis**.

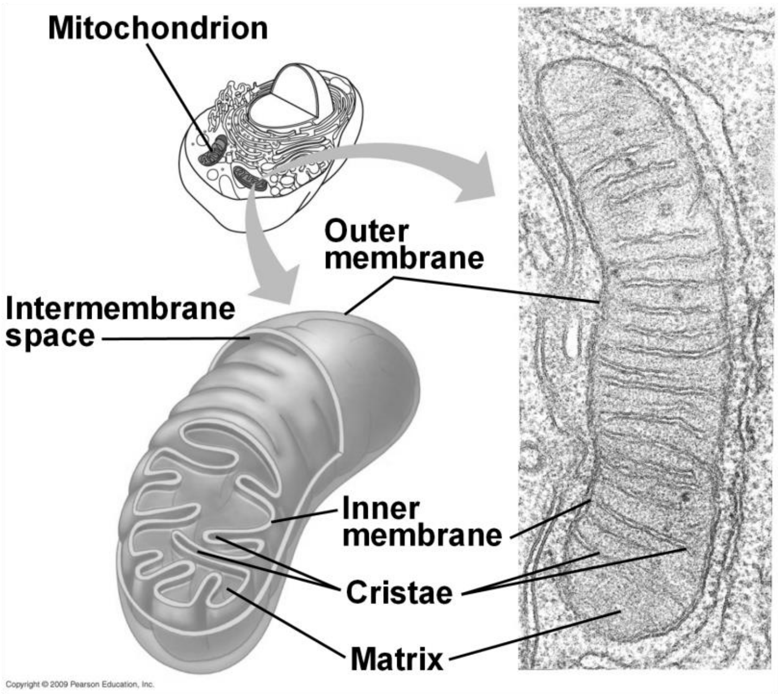


Fig. 18 Structure of mitochondrion

2.9] CHLOROPLAST
This organelle is found in photosynthetic organisms like algae and plants.

A. STRUCTURE
- Two membranes enclose the **intermembrane space**.
- Inside the chloroplast is **a system of flattened sacs** known as the **thylakoid membrane** (Fig.19). This membranous system forms stacks called **granum** (plural: grana), with **intergranal lamellae** between the grana. (Fig. 19)
- The fluid surrounding the thylakoid membrane is the **stroma**, which contains the **DNA** of the chloroplast, **70S ribosomes**, enzymes for Calvin cycle and **starch grains**.

A. FUNCTION
1. Chloroplasts are the **sites of photosynthesis**.
2. The light-dependent reactions of photosynthesis occur at the thylakoid membrane while the light-independent reactions occur in the stroma.

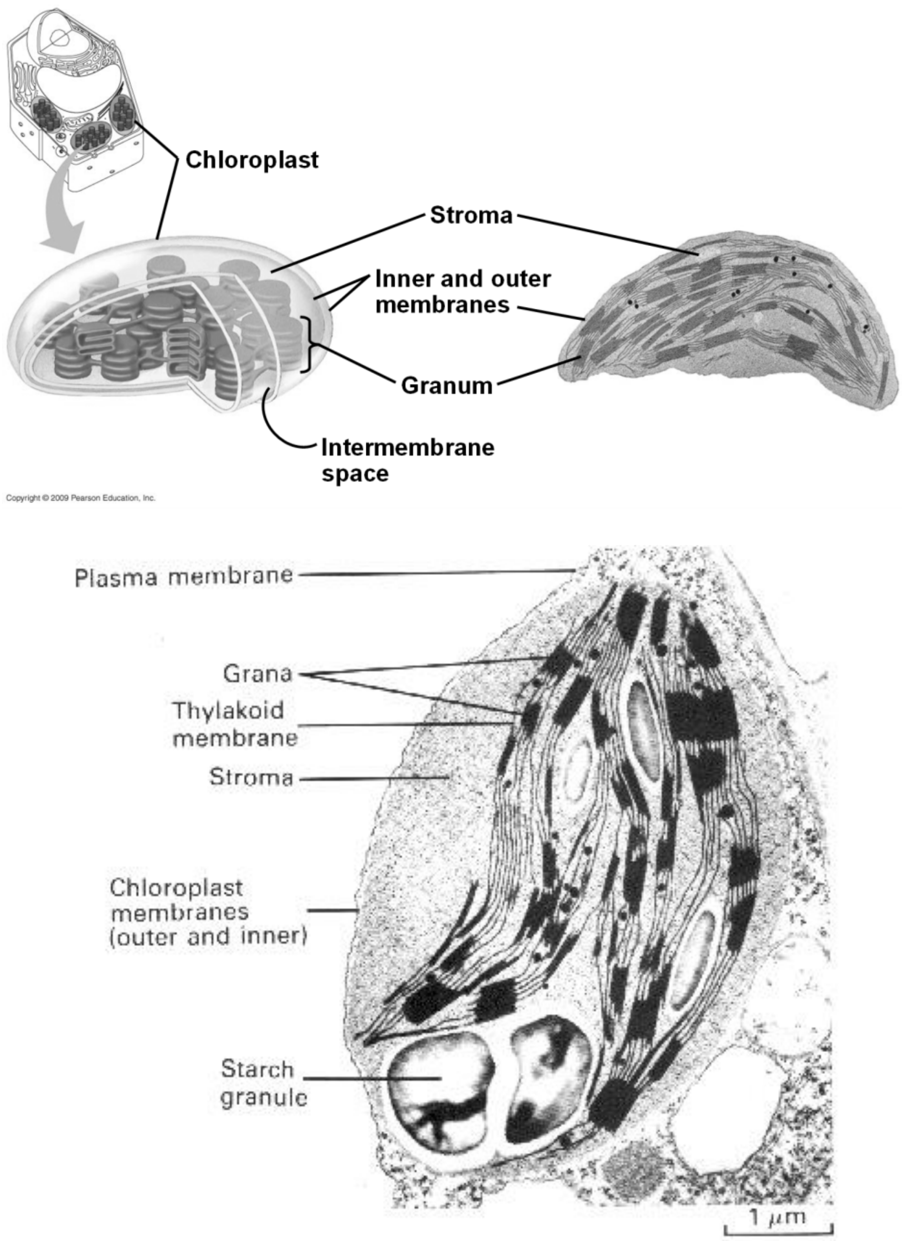


Fig. 19 Structure of a chloroplast

2.10] ENDOMEMBRANE SYSTEM

- The endomembrane system is a series of closed membranes within eukaryotic cells that are either **continuous** with each other or communicate with one another **via vesicles** which are formed at one surface and move to a second where they are incorporated.

A. STRUCTURE

- Organelles that are part of the endomembrane system include: **nuclear envelope**, **endoplasmic reticulum** (both smooth and rough endoplasmic reticulum), **Golgi body**, **vesicles**, **lysosomes**, **various kinds of vesicles and vacuoles and cell surface membrane**.

  Note: Mitochondria and chloroplast are **NOT** part of the endomembrane system.

B. FUNCTION

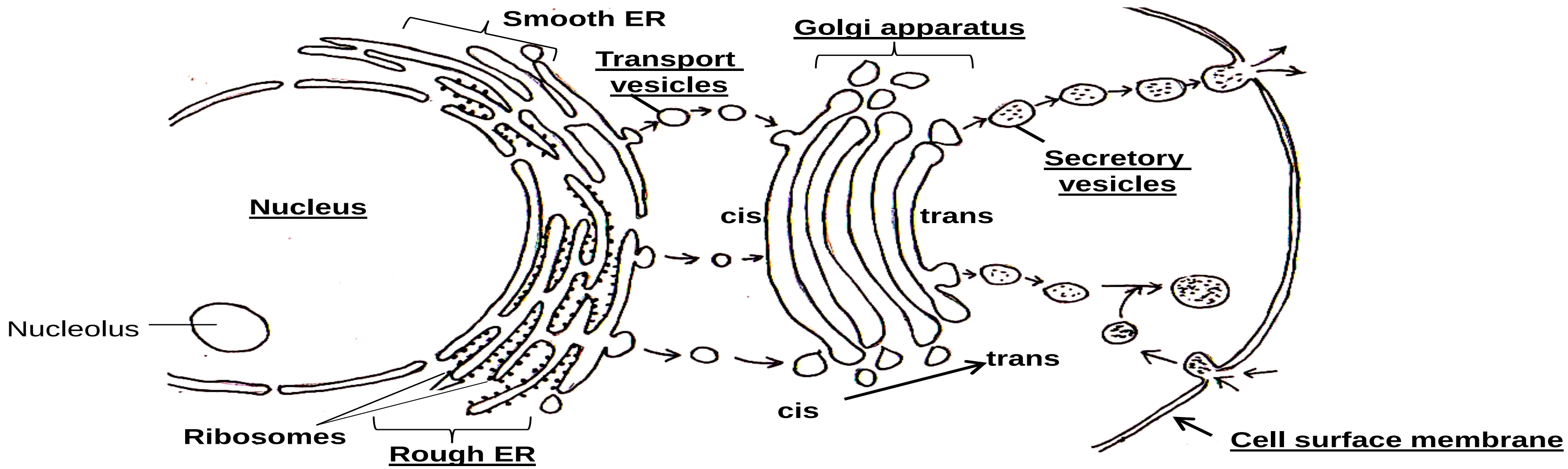
- 2 main functions of the Endomembrane System are as follows:

  a) SYNTHESIS AND TRANSPORT OF SECRETORY PROTEINS

  b) FORMATION OF LYSOSOME

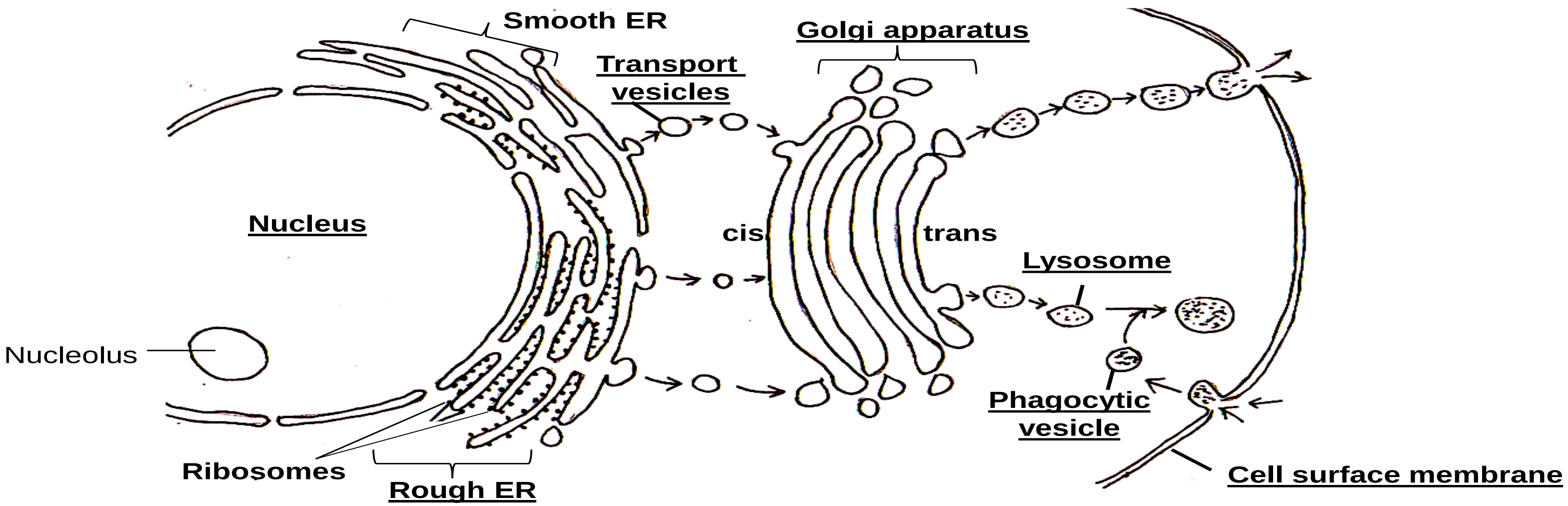
  Please refer to the 2 diagrams on the next 2 pages

a) SYNTHESIS AND TRANSPORT OF SECRETORY PROTEINS



ORGANELLE IN ENDOMEMBRANE SYSTEM	NUCLEUS	ROUGH ENDOPLASMIC RETICULUM (RER)	TRANSPORT VESICLE	GOLGI APPARATUS	SECRETORY VESICLE	CELL SURFACE MEMBRANE
SYNTHESIS AND TRANSPORT OF SECRETORY PROTEINS	1. **Gene** coding for protein is being **transcribed into mRNA in the nucleus**. 2. mRNA from the **passes through the pores of the nuclear envelope to the ribosomes** found on the Rough Endoplasmic Reticulum (RER).	3. **Ribosomes** found on the RER **translates mRNA to form a polypeptide chain**. 4. Polypeptide chain is being passed **from the ribosome directly into the lumen** of the RER. 5. Polypeptide chain **undergoes folding in the cisternae into its 3D shape** and may **undergo chemical modification/post-translational modification**.	6. The folded polypeptide chain is then **packaged into a transport vesicle** and it buds out from the RER. 7. The transport vesicle moves from the RER to the Golgi apparatus.	8. Transport vesicle **fuses with the cis face** of the Golgi apparatus. 9. Polypeptide is then being **transported from the cis to the trans face** of the Golgi apparatus, through a series of transport vesicles. 10. Within the cisternae of the Golgi apparatus, the polypeptide chain **undergoes sorting, packaging and chemical modification/post-translational** modification by adding/deleting and/or substituting sugar residues on the polypeptide chain.	11. The protein is then being **packaged into a secretory vesicle**, and it buds **out from the trans face of the Golgi apparatus**.	12. The secretory vesicle then **moves to the cell surface membrane t**hrough the **help of the cytoskeleton**. 13. **Secretory vesicle fuses with the cell surface membrane** of the cell and **releases the protein out of the cell through exocytosis**.

b) FORMATION OF LYSOSOME



ORGANELLE IN ENDOMEMBRANE SYSTEM	NUCLEUS	ROUGH ENDOPLASMIC RETICULUM (RER)	TRANSPORT VESICLE	GOLGI APPARATUS	LYSOSOME
HOW A PROTEIN SYNTHESIS AND MODIFICATION	1. **Genes** coding for enzymes in lysosome are **being transcribed into mRNA** in the nucleus. 2. mRNA **pass through the pores of the nuclear envelope to the ribosomes** found on the Rough Endoplasmic Reticulum (RER).	3. **Ribosomes** found on the RER **translates mRNA to form polypeptide chains**. 4. Polypeptide chains are being passed **from the ribosome directly into the lumen** of the RER. 5. Polypeptide chains **undergo folding in the cisternae into its 3D shape** and may **undergo chemical modification/post-translational modification.**	6. The folded polypeptide chains are then **packaged into a transport vesicle** and it buds out from the RER. 7. The transport vesicle moves from the RER to the Golgi apparatus.	8. Transport vesicle **fuses with the cis face** of the Golgi apparatus. 9. Polypeptides are then being **transported from the cis to the trans face** of the Golgi apparatus, through a series of transport vesicles. 10. Within the cisternae of the Golgi apparatus, the polypeptide chain **undergoes sorting, packaging and chemical modification/post-translational** modification by adding/deleting and/or substituting sugar residues on the polypeptide chain.	11. The enzyme protein is then being **packaged into a lysosome**, and it **buds out from the trans face of the Golgi apparatus**. 12. The lysosome then fuses with the phagocytic vesicle and the enzymes from the lysosome hydrolyses the contents of the phagocytic vesicle. 13. **The products of hydrolysis are released into the cytoplasm.**

3] PROKARYOTES (BACTERIA)

Prokaryotes (Bacteria)	**LO (d)** Describe the **structure of a typical bacterial cell** (small and unicellular, peptidoglycan cell wall, circular DNA, 70S ribosomes and lack of membrane-bound organelles).

PROKARYOTES are **unicellular organisms** (as opposed to multicellular organisms) which are **small** and **well organized**, capable of achieving all of an organism's life functions within a single cell. The most common example of prokaryotic organisms is the **bacteria**, which is used as the model organism to study prokaryotes.

Most prokaryotes are unicellular, although the cells of some species remain attached to each other after cell division. **Prokaryotic cells** typically have diameters of 0.5 - 5 µm, **much smaller than** the 10 - 100 µm diameter of many **eukaryotic cells**.

Prokaryotic cells **have a variety of shapes** (Fig. 20).

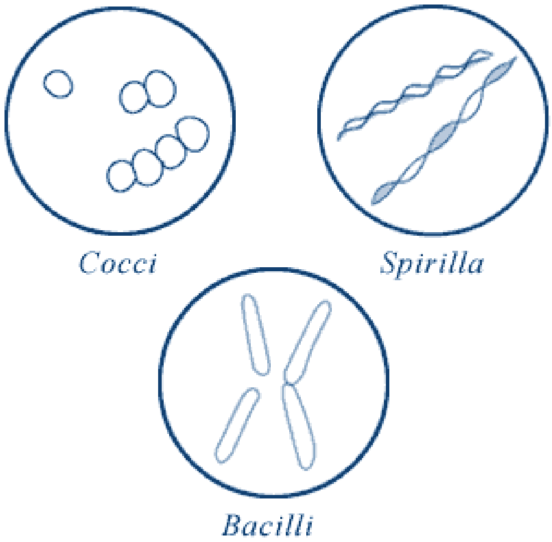


Fig. 20: The most common shapes of prokaryotes

(a) Cocci (singular, *coccus*) are spherical prokaryotes. They occur singly, in pairs (diplococci), in chains of many cells (streptococci), and in clusters resembling bunches of grapes (staphylococci).

(b) Bacilli (singular, *bacillus*) are rod-shaped prokaryotes. They are usually solitary, but in some forms the rods are arranged in chains (*streptobacilli*).

(c) Spiral prokaryotes include spirilla, which range from comma-like shapes to loose coils, and spirochetes, which are corkscrew-shaped.

Prokaryotes are made of cells that **lacks a true nucleus**. The genetic material of a prokaryotic cell is a **circular DNA molecule**, which is not enclosed within a membrane but lies freely in the cytoplasm, in a region called the **nucleoid**. They **also lack membrane bound organelles**. Nearly all prokaryotes contain a **cell wall** made of **peptidoglycan**, which is surrounded by the **capsule** (Fig. 20a and 20b).

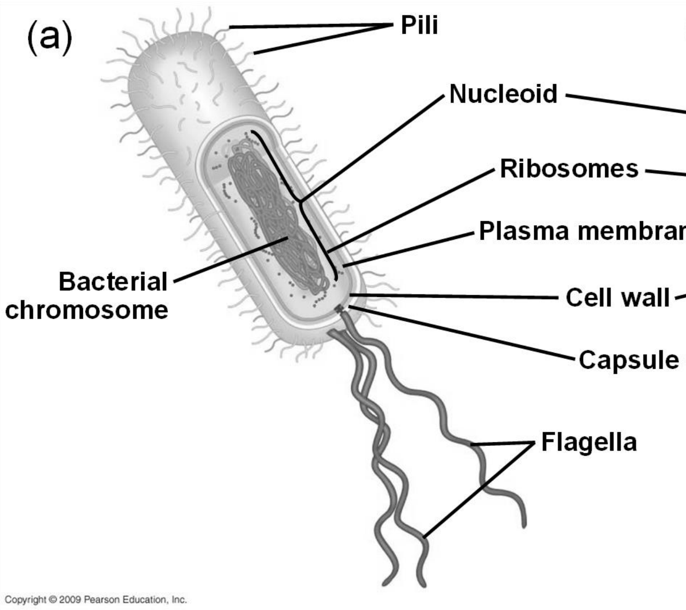


Fig.20a: Drawing of a Prokaryotic cell – Bacteria

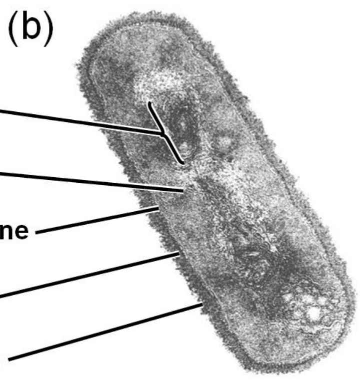


Fig.20b: Electron Micrograph of bacterium *Bacillus coagulans*

3.1] PROKARYOTIC STRUCTURE – CELL WALL

A. STRUCTURE

- Most bacterial cell walls contain **peptidoglycan**, a polymer composed of **modified sugars cross-linked by short polypeptides** (Fig. 21)**.**

  Note: This is in contrast to that found in eukaryotes that have cell walls, such as plants and fungi, where the walls are usually made of cellulose or chitin.

B. FUNCTION

- **The prokaryotic cell wall** provides structural support and help prevents prokaryotes from bursting in an aquatic (hypotonic) environment, where water enters the cell, much like the cell walls of plants.

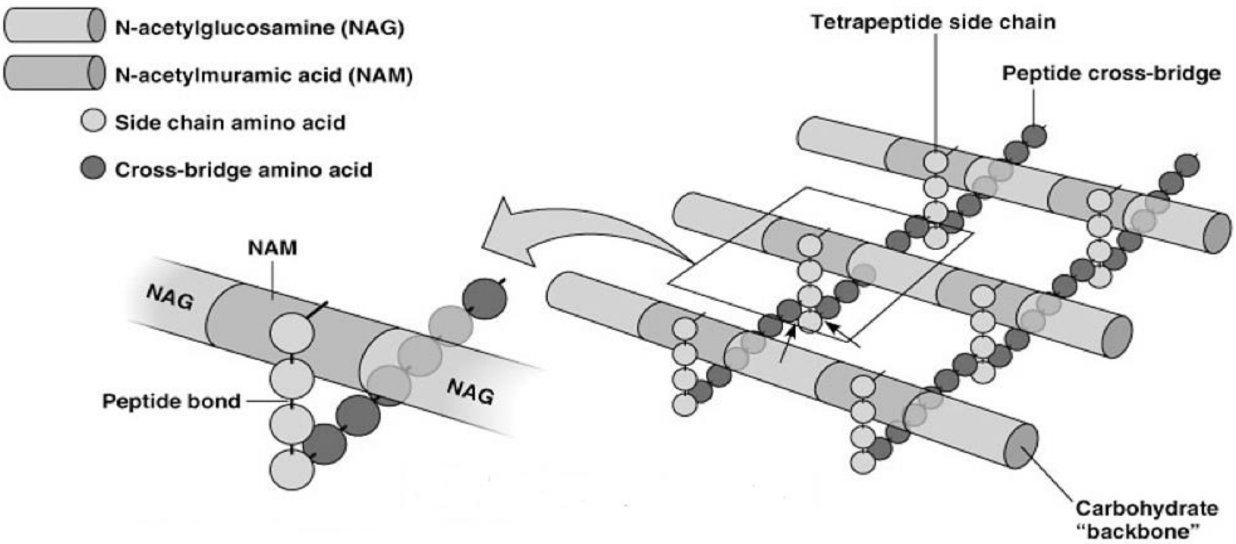


Fig. 21 Peptidoglycan cell wall of Gram Positive Bacteria

3.2] PROKARYOTES (BACTERIA) – GENOME: NUCLEOID & PLASMIDS

A. STRUCTURE

- Unlike eukaryotes, prokaryotes lack a membrane-bounded nucleus; their chromosome is located in the **nucleoid**, a region of cytoplasm that appears lighter than the surrounding cytoplasm in electron micrographs (Fig. 20).
- In majority of prokaryotes, this **nucleoid region** contains a single **circular chromosome** with fewer proteins as compared to the linear chromosomes of eukaryotes (Fig. 23).
- In addition to its single chromosome, the genome of a typical prokaryotic cell may also have rings of **plasmids** (Fig. 22) that are much smaller in size, mostly carrying only a few genes. These plasmids can replicate independently of the circular chromosome.

B. FUNCTION

- The genome of prokaryotes functions similarly to that of eukaryotes, containing the DNA that holds the genetic information for the prokaryotes.

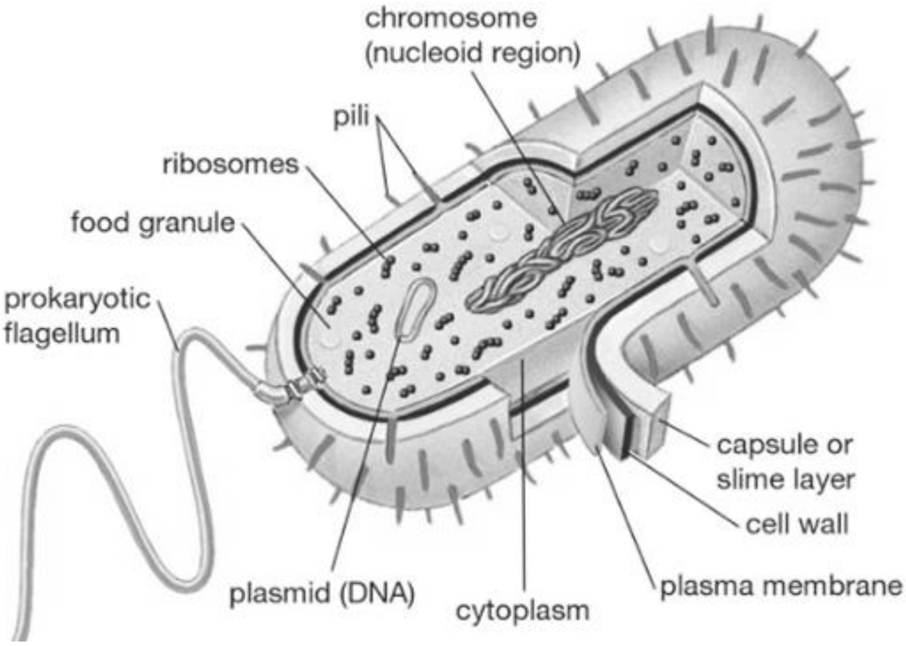


Fig. 22 A prokaryotic chromosome and plasmid

3.3] PROKARYOTES (BACTERIA) – 70S RIBOSOME

- Unlike eukaryotes, prokaryotes contain the 70S ribosome is made up of a 30S small ribosomal subunit and a 50S large ribosomal subunit.
- The 70S ribosome in prokaryotes is slightly smaller than that in eukaryotes.
- This functions similarly to the ribosomes of eukaryotes.

4] COMPARISON BETWEEN PROKARYOTES AND EUKARYOTES

CONCEPT MAP FOR PROKARYOTES AND EUKARYOTES

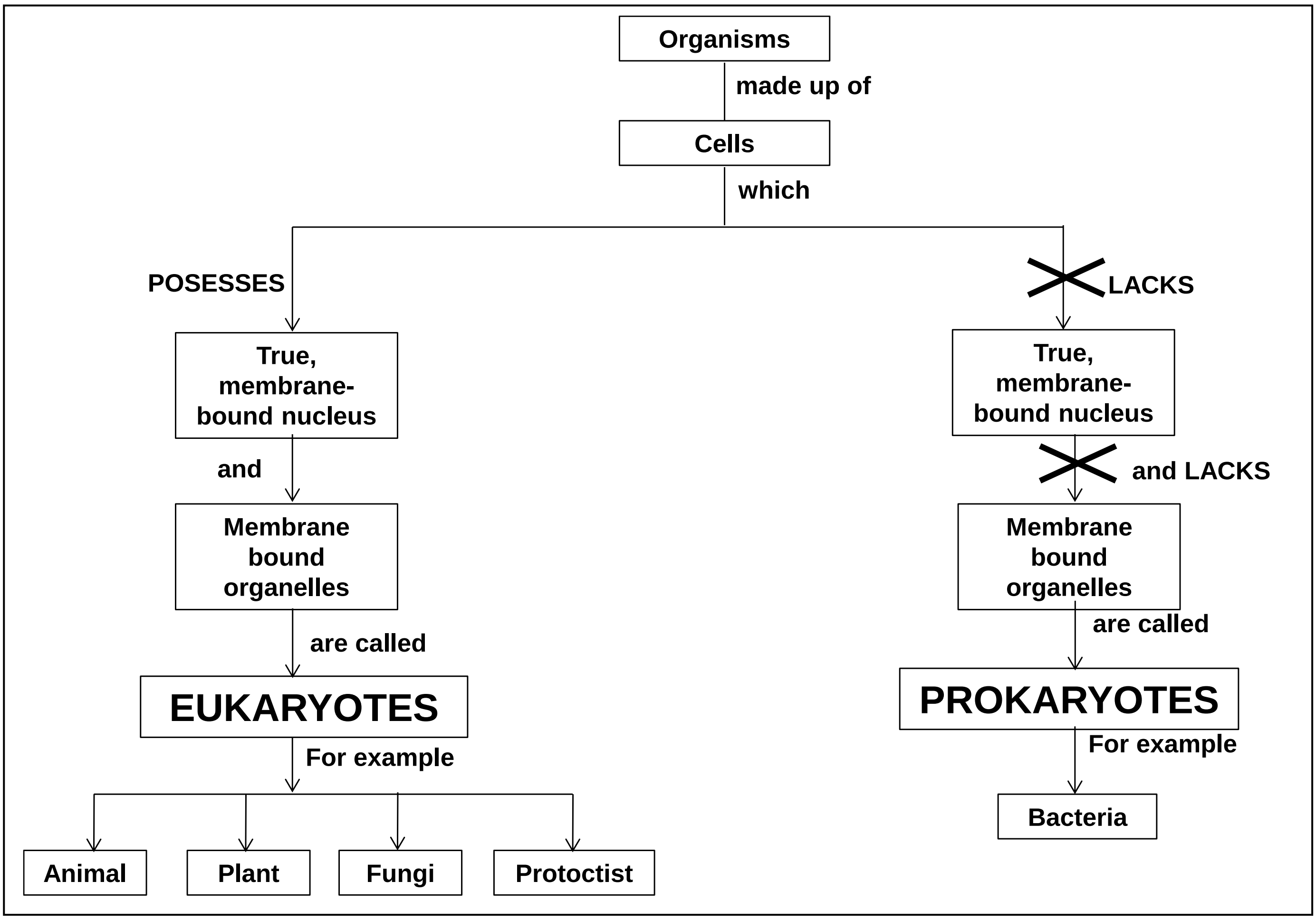


TABLE OF COMPARISON BETWEEN PROKARYOTES AND EUKARYOTES

FEATURES	PROKARYOTIC CELLS	EUKARYOTIC CELLS
Cell Size	▪ Smaller, with diameter ranging from **0.5 µm to 10 µm**.	▪ Larger, with diameter ranging from **10 µm to 100 µm**.
Cell wall	▪ Cell wall is made of **peptidoglycan**.	▪ Plant cell wall is made of **cellulose** while fungal cell wall is made of chitin.
Organelles	▪ No membrane-bound organelles.	▪ Membrane-bound organelles are present (e.g. nucleus, mitochondrion, endoplasmic reticulum and Golgi body).
Genetic material	▪ No nucleus, only has a nucleoid region. ▪ Circular DNA molecule lying free in the cytoplasm in nucleoid region. ▪ DNA associated with non-histone proteins.	▪ Nucleus is present. ▪ DNA molecule is linear. ▪ DNA molecule is associated with proteins (histones) to form chromatin
Ribosomes	▪ Smaller, with sedimentation coefficient of **70S**.	▪ Larger, with sedimentation coefficient of **80S**.
Respiration	▪ Mesosome present for respiration.	▪ Mitochondria present for respiration.
Photosynthesis	▪ Photosynthetic membranes present for photosynthesis.	▪ Chloroplast present for photosynthesis.
Flagellum	▪ Simple, lacking microtubules and extracellular (i.e. not enclosed by a cell surface membrane). ▪ Diameter of 20nm.	▪ Complex, with “9+2” arrangement of microtubules and intracellular (i.e. surrounded by cell surface membrane). ▪ Diameter of 200nm.

5] VIRUSES

Viruses	**LO (e)** Describe the structural components of viruses, including enveloped viruses and bacteriophages, and interpret drawings and photographs of them.

5.1] STRUCTURAL COMPONENTS OF VIRUSES

- Viruses range in size from about 20 nm – 300 nm. They cannot be seen with the light microscope and can pass through filters which retain bacteria.
- **A virus is basically made up of a genome (made up of DNA or RNA) enclosed within a protective coat (made up of proteins).**
- Viruses have a simple structure consisting of: **core** (i.e. viral genome), **capsid** (made up of **capsomeres**), collectively forming the **nucleocapsid** and (sometimes) **envelope**. Viruses that consists only nucleocapsid are called **naked viruses** and viruses that have an envelope surrounding their nucleocapsid are known as **enveloped viruses**.

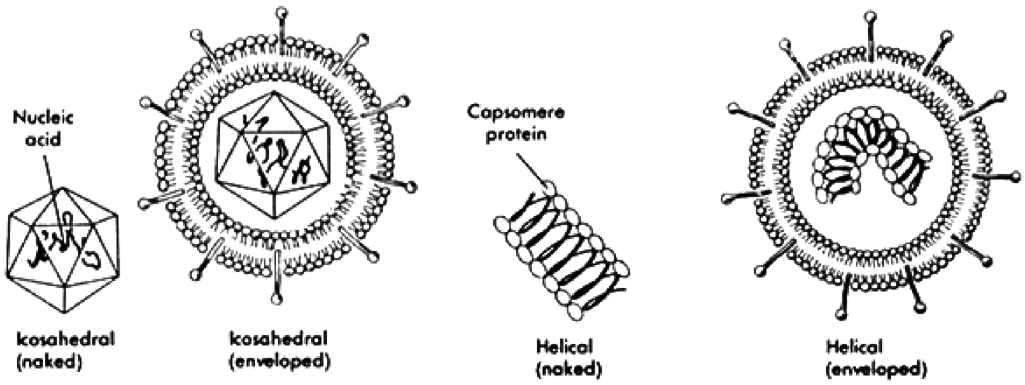


Fig. 23 Examples of enveloped and naked viruses

i. Main structural components of viruses
   i. **Core** –The genome of a virus may consist of DNA or RNA, which may be single stranded (ss) or double stranded (ds), linear or circular. The entire genome may occupy either one nucleic acid molecule or several nucleic acid segments

   ii. **Capsid** – a protective coat of **protein** surrounding the core, i.e. viral genome. Capsids can come in many forms, some are **helical** (tobacco mosaic virus), some are **icosahedral** (adenoviruses) and others are **complex** (bacteriophage T4).

   iii. **Capsomeres** – capsids are often built up through self-assembly of identical repeating subunits called capsomeres. Capsomeres are coded by the viral genome.

   iv. **Nucleocapsid –** the combined structure formed by the core and capsid.

   v. **Envelope** – viruses, such as the HIV and influenza viruses, have an additional lipoprotein layer around the capsid derived from the cell surface membrane of the host cell. Viral envelopes are derived from **cellular membranes** and are acquired when nucleocapsids leave a cell by budding or exocytosis.

ii. A full assembled and complete virus is known as a **virion.**

5.2] EXAMPLES OF VIRUSES

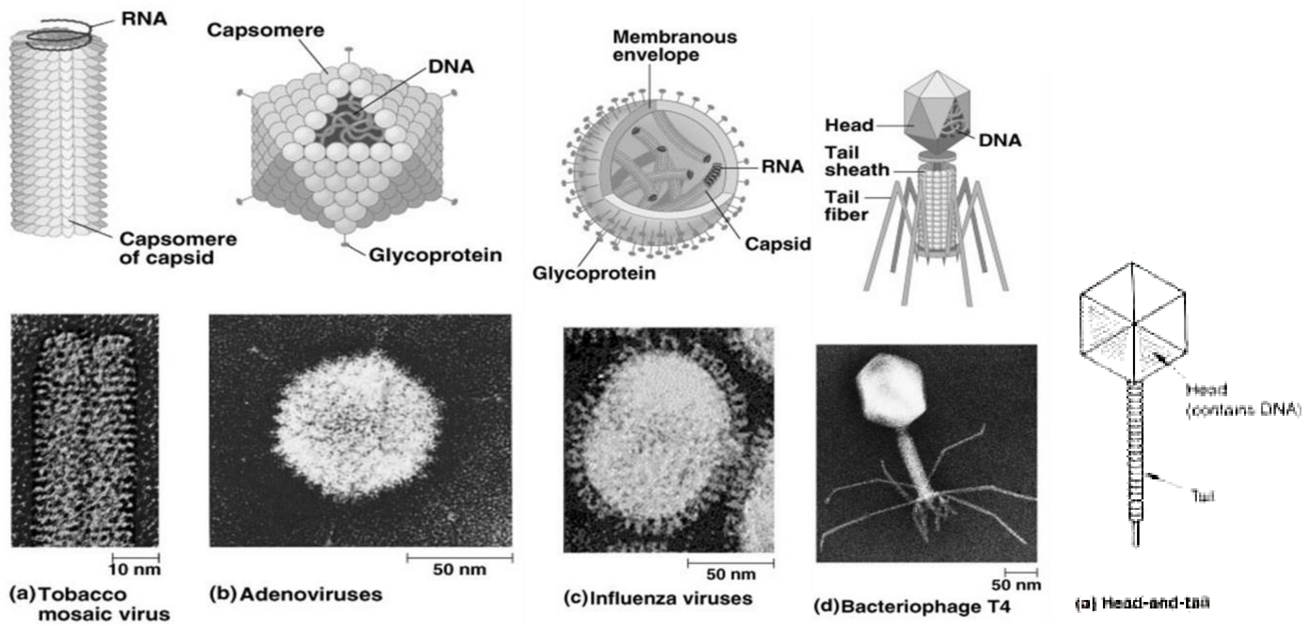


Fig. 24 (a) TMV (b) Adenoviruses (c) Influenza (d) Bacteriophage (e) Lambda phage

Feature	T4 phage	lambda (λ) phage	Influenza virus	HIV	tobacco mosaic virus
Core	dsDNA	dsDNA	ssRNA	ssRNA	ssRNA
Capsid	Complex (Icosahedral head and tail apparatus)	Complex (Icosahedral head and tail apparatus)	Helical	Conical	Helical
Envelope	Absent	Absent	Present	Present	Absent

* ds – double stranded; ss – single-stranded

5.3] STRUCTURE OF BACTERIOPHAGES

5.3.1] T4 PHAGE (Fig. 25)

Structural components	T4 phage	Special Features
Core	Double stranded DNA	
Capsid	Complex (Icosahedral head and tail apparatus)	**Tail portion** of the capsid that is involved in attachment to the host cell comprises of: - a **contractile sheath** - a **base plate** with attached **tail pins** - several **tail fibres**
Envelope	Absent	

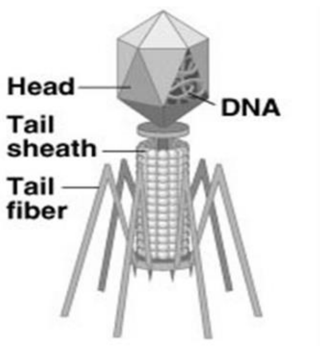


Fig. 25a Components of T4 phage

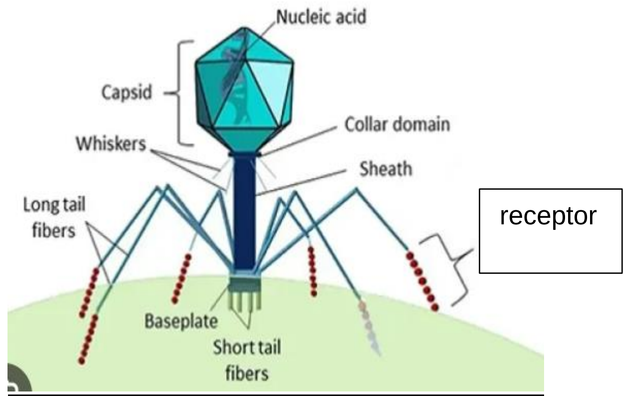


Fig. 25b Electronmicrograph of T4 phage

5.3.2] LAMBDA PHAGE (Fig. 26)

Structural components	Lambda phage	Special Features
Core	Double stranded DNA	
Capsid	Complex (Icosahedral head and tail apparatus)	**Tail portion** of the capsid that is involved in attachment to the host cell comprises of: - a **contractile sheath** - a **base plate** with attached **tail pins** - one short **tail fiber**
Envelope	Absent	

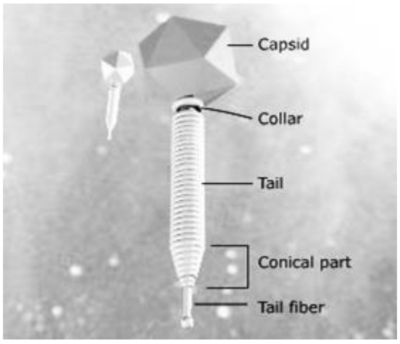


Fig. 26a Structure of phage lambda (λ)

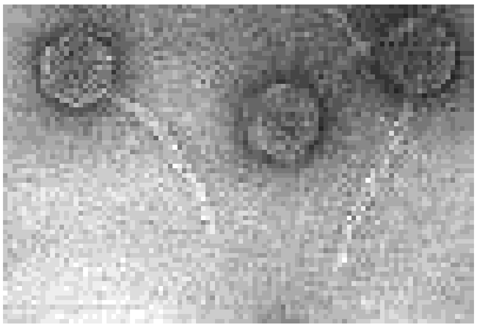
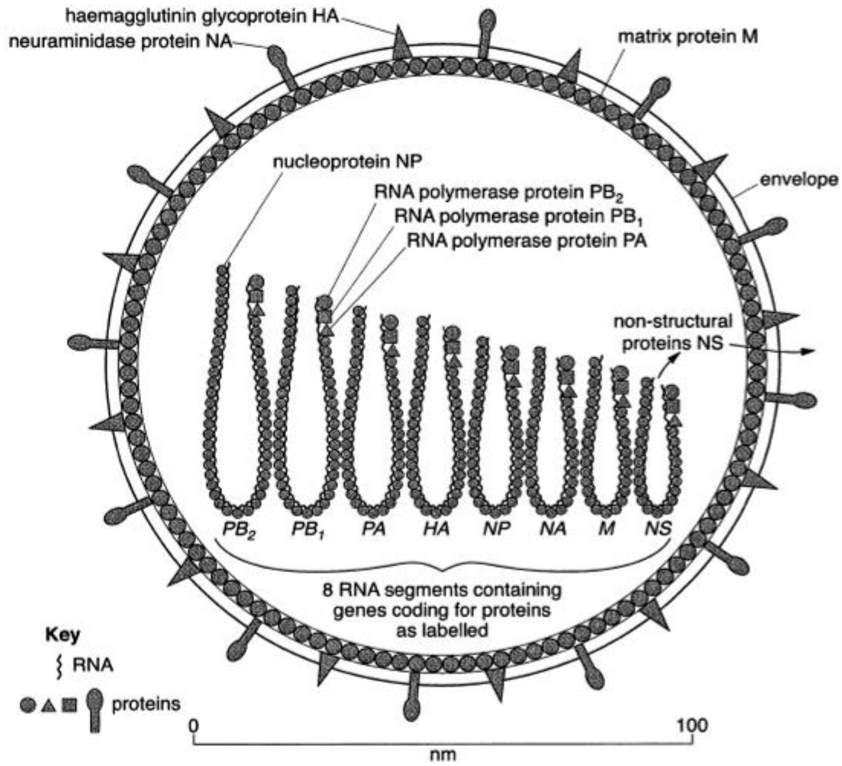


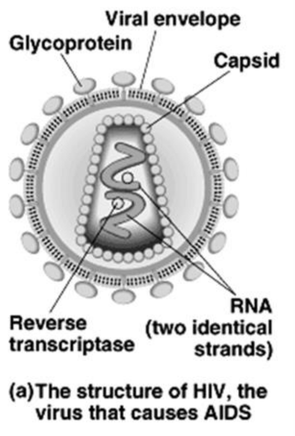
Fig. 26b Electronmicrograph of phage lambda (λ)

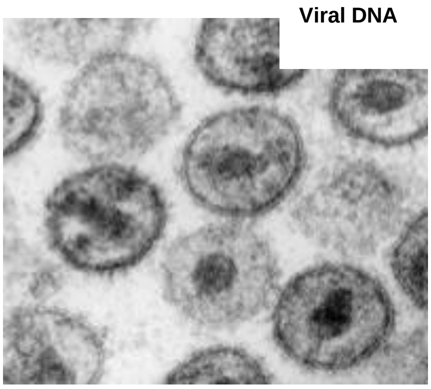
5.4] STRUCTURE OF ANIMAL VIRUSES (ENVELOPED VIRUSES)

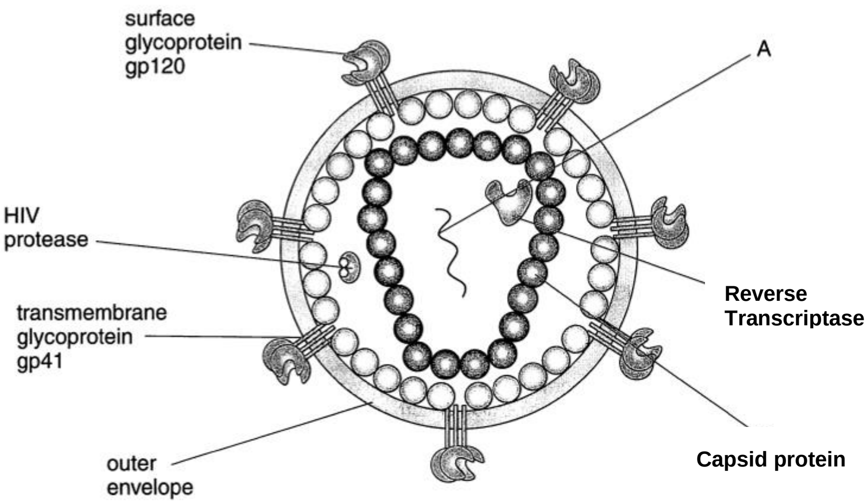
5.4.1] STRUCTURE OF INFLUENZA VIRUS

Structural components	Influenza Virus	Structure
Core	8 Single stranded linear RNA segments	 Fig. 27 Structure of Influenza virus
Capsid	Helical	
Envelope	Contain viral **glycoproteins** protrude from the outer surface of this envelope and **bind to specific receptor molecules** on the surface of a host cell.	
Enzymes	RNA-dependent RNA Polymerase	

5.4.2] STRUCTURE OF HUMAN IMMUNODEFICIENCY VIRUS (HIV)

<table>
<tr><th>Structural components</th><th>HIV</th><th>Structure</th></tr>
<tr><td>Core</td><td>Single stranded linear RNA
(2 identical viral RNA strands)</td><td rowspan="4">




<u>Fig 28a Structure of HIV</u> <u>Fig 28b Electron Micrograph of HIV</u>


<u>Fig. 28a Structure of HIV</u>
</td></tr>
<tr><td>Capsid</td><td>Conical</td></tr>
<tr><td>Envelope</td><td>Consist of viral glycoproteins protrude from the outer surface of this envelope and bind to specific receptor molecules on the surface of specific types of white blood cells.</td></tr>
<tr><td>Enzymes</td><td>●Reverse transcriptase
●HIV Protease
●Integrase</td></tr>
</table>

5.5] VIRUSES CHALLENGE THE CELL THEORY

Cell Theory	**LO (f)** Discuss **how viruses challenge the cell theory** and concepts of what is considered living.

IN YOUR TUTORIAL GROUPS, PREPARE THIS QUESTION AS PART OF ESSAY QUESTION BEFORE YOUR TUTORIAL LESSON.

The cell theory of **life:**

A **scientific theory** is an explanation of an aspect of the natural world that can be *repeatedly tested* and verified in accordance with the scientific method, using accepted protocols of observation, measurement, and evaluation of results. Where possible, theories are tested under controlled conditions in an experiment. Here, the cell theory attempts to explain what constitutes a living organism.

The cell theory of life can be summarised by three main principles:

1. **The cell is the smallest, most basic unit of life.**

2. **All living organisms are composed of cells.**

3. **All cells arise from pre-existing cells by cell division.**

Therefore, according to the cell theory, all life must comprise cells and anything that is less than a cell (e.g. a nucleus, a mitochondrion, a chloroplast) is not considered a living thing.

As viruses can replicate within host cells and cause many biological effects on living hosts, much like parasites, they are often considered in the grey area at the boundary of what is living and non-living (biochemical molecules). Thus, viruses are often used as the main example that challenges the cell theory of life.

[For tutorial]

Discuss **how viruses challenge the cell theory** and concepts of what is considered alive.

- Guiding points: Refer back to 3 fundamental principles of cell theory and how if viruses are considered living things, it challenges this theory.

6] EXPERIMENTAL SKILLS & MISCELLANEOUS

6.1] UNITS OF MEASUREMENT

UNITS OF MEASUREMENT of length in cell studies are as follows:
- 1 millimetre (mm) = 10^{-3} metre (m)
- 1 micrometre (μm) = 10^{-3} mm = 10^{-6} metre (m)
- 1 nanometre (nm) = 10^{-3} μm = 10^{-9} metre (m)

TRY THIS OUT!

Q1. Convert 500 μm into metres.

Q2. Convert 788 nm into millimetres.

The approximate diameters of cells and their components are listed in Table 1.

Table 1: Approximate diameters of cells and their components

Cells and their components	Diameter
Plant cell	40 μm
Animal cell	20 μm
Nucleus	10 μm to 20 μm
Bacterium	1 μm
Mitochondrion	0.5 μm to 1.5 μm
Lysosome	0.2 μm to 0.5 μm
Ribosome	20 nm
DNA molecule	2 nm

6.2] MICROSCOPY

Cells are extremely small, and can only be seen with a microscope (Fig.1). There are two types of microscopes, the **light microscope** and the **electron microscope**.

LIGHT MICROSCOPE is a type of microscope which uses visible light and a system of lenses to magnify images of small samples.

- Specimens can be magnified up to 1,000 times the actual size of the specimen.
- The resolution of the light microscope, however, is too low to show details on some of the cell's smaller structures (i.e. the ultrastructures).

ELECTRON MICROSCOPE [EM] is a type of microscope that uses an electron beam to illuminate a specimen and produce a magnified image.

- Electron microscopes have a higher resolution than light microscopes, and can resolve biological structures as small as 2 nanometres and can magnify up to 100,000 times.
- The fine structure of cells, known as **ultrastructure**, was largely discovered using the technique of electron microscopy.
- Two EM microscopes are routinely used. One is the transmission electron microscope (TEM), which is used to study internal cell structure, and the other is the scanning electron microscope (SEM), which is used to study the architecture of cell surfaces.

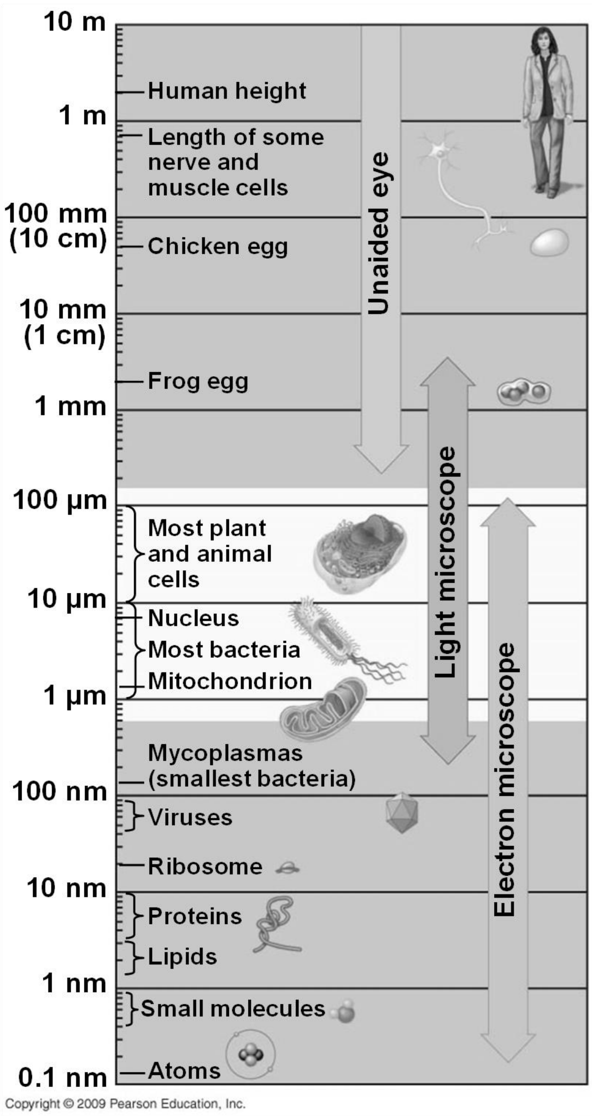


Fig.1: The sizes of cells and related objects

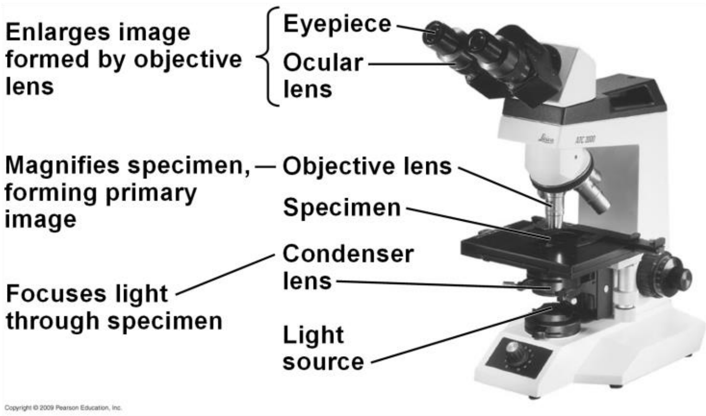


Fig.2: Light Microscope

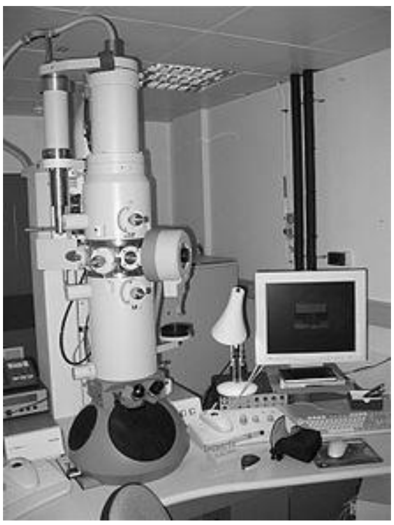


Fig.3: Electron Microscope

6.3] CALCULATING MAGNIFICATION

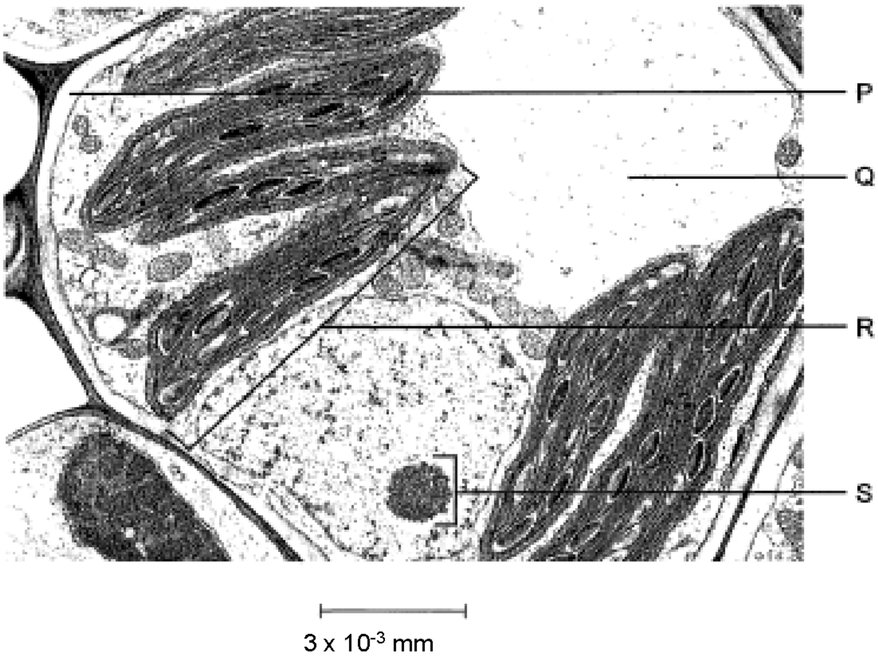
Candidates may be presented with a magnified image as seen under a light microscope or an electron microscope and be required to calculate the actual size of the image.

MAGNIFICATION is the ratio of an object's image size to its real size.

MAGNIFICATION = IMAGE SIZE OF OBJECT/ ACTUAL SIZE OF OBJECT

[A-LEVEL 2006/P1/Q4]

The diagram shows part of a plant cell as seen under an electron micrope, and a scale bar showing 3 x 10^{-3} mm.



What is the approximate length of the nucleolus, S, in μm?

6.4] CELL FRACTIONATION

CELL FRACTIONATION is used to isolate (fractionate) cell components based on **size** and **density**.

TECHNIQUE OF CELL FRACTIONATION (Fig. 4)

- The instrument used to fractionate cell components is called a **centrifuge**.

  A CENTRIFUGE spins test tubes holding mixtures of disrupted cells at a **series of increasing speeds**. At each speed, the **resulting force causes a fraction** of the cell components to settle to the bottom of the tube, **forming a pellet**.
- The higher the speed of centrifugation, the higher the force at which the cell components are isolated.
- The **smaller the cell components**, the **larger the force required to isolate them**; hence **a higher speed is used to isolate smaller cell components.**
- At lower speeds, the pellet consists of larger components, and higher speeds yield a pellet with smaller components.

APPLICATION OF CELL FRACTIONATION
- Cell fractionation enables researchers to prepare specific cell components in bulk and identify their functions, a task not usually possible with intact cells.

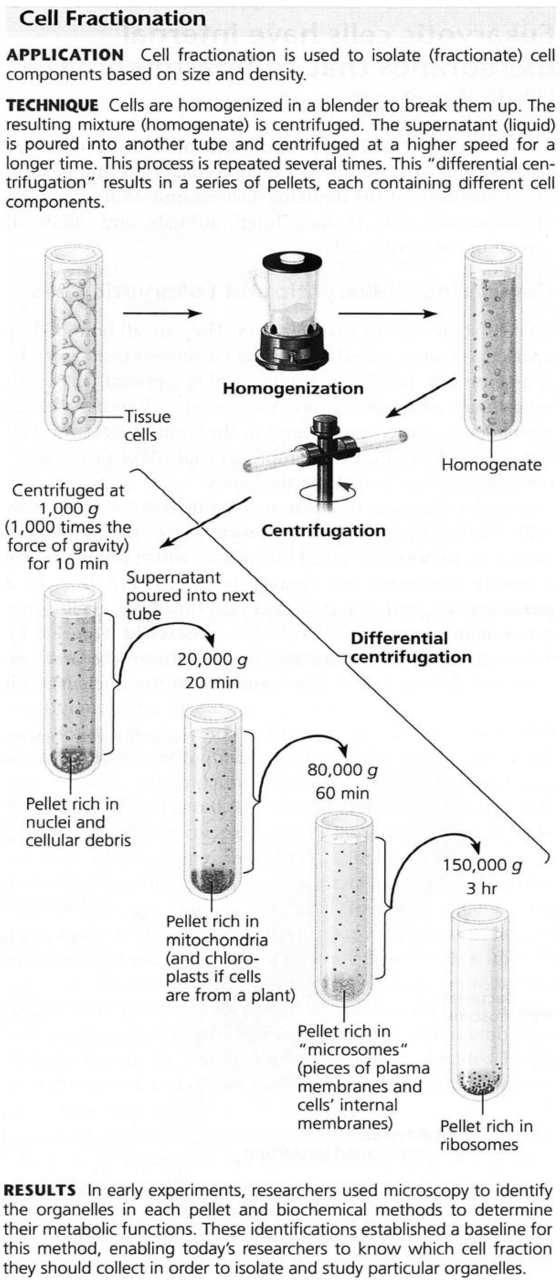


Fig.4: Cell Fractionation

6.5] ENDOSYMBIOTIC THEORY

- Symbiosis occurs when two different species benefit from living and working together.
- When one organism actually lives *inside* the other it is called **endosymbiosis**.
- There is evidence that mitochondria and chloroplasts were once primitive bacterial cells. Over millions of years of evolution, mitochondria and chloroplasts have become more specialized and today they reside within the eukaryotic cells
- Hence, the endosymbiotic theory explains that the mitochondria of eukaryotes and the chloroplasts of green plants originated as free-living prokaryotes that invaded primitive eukaryotic cells and become established as permanent symbionts in their cytoplasm. (Fig.23)

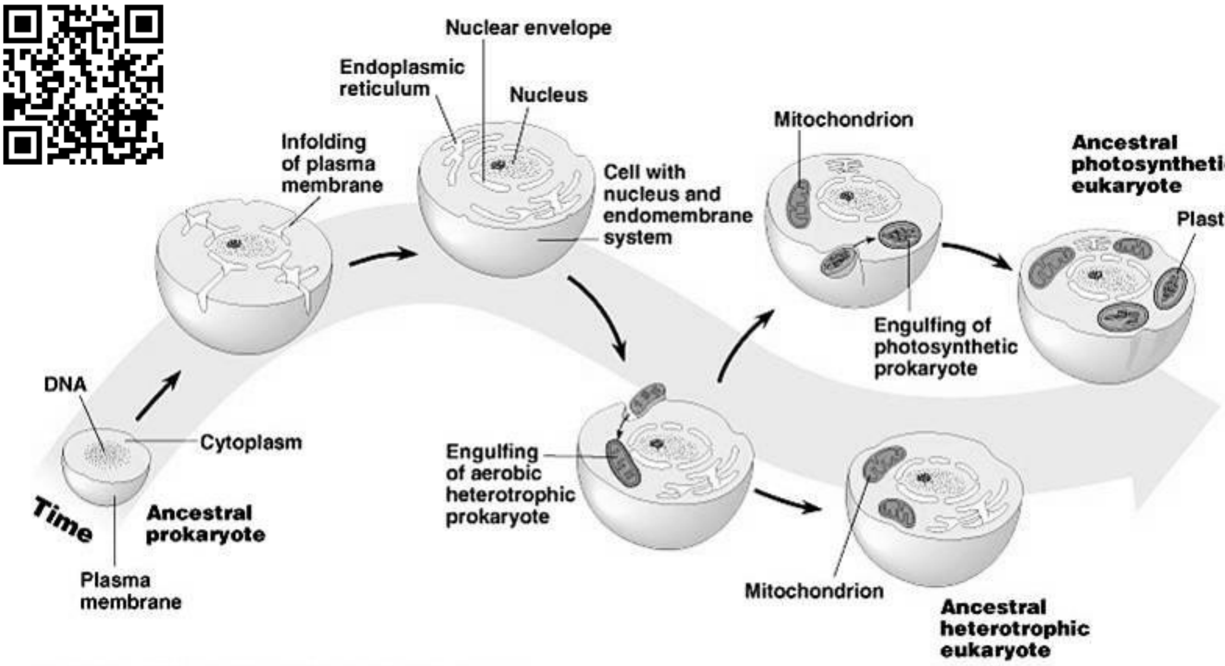


Fig.23: The Endosymbiotic Theory

Think: What evidence would support this theory that these organelles were once prokaryotes?

- Evidence supporting this theory:
  i. Both mitochondria & chloroplasts contain their own DNA and ribosomes. DNA of these organelles resembles those of prokaryotes: both are circular, not wound on proteins & not enclosed by nuclear envelope.
  ii. Ribosomes of mitochondria & chloroplasts are smaller (70S) & more similar to prokaryotes than ribosomes (80S) of eukaryotes.
  iii. Mitochondria & chloroplasts divide by binary fission like bacteria.