UNIT-III

ULTRASTRUCTURE AND FUNCTIONS OF ENDOPLASMIC RETICULUM

Introduction

- Endoplasmic reticulum is a network of membrane bound cavities, vesicles and tubules, distributed throughout the cytoplasm.
- It is concerned with the biosynthesis of proteins and lipids
- It is more concentrated in the endoplasm than in the ectoplasm. Hence the name
- The term endoplasmic reticulum (ER) was introduced by Porter 1948
- According to Porter, the endoplasmic reticulum is a complex, finely divided vacuolar system extending from the nucleus throughout the cytoplasm to the margin of the cell
- Since this network is more concentrated in the endoplasm of the cytoplasm, the name endoplasmic reticulum was proposed
- De Robertis, Nowinski and Saez have coined another term, the cytoplasmic vacuolar system for this membrane bound cavities present in the cytoplasm
- Endoplasmic reticulum is absent from ***eggs, embryonic cells, RBC*** and ***bacteria***

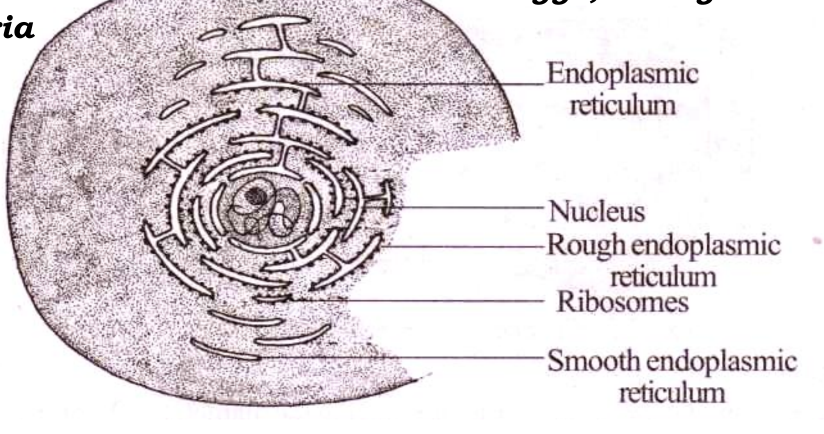


Fig. A cell showing endoplasmic reticulum

Structure

- Endoplasmic reticulum consists of three components.
- They are ***cisternae, vesicles*** and ***tubules***

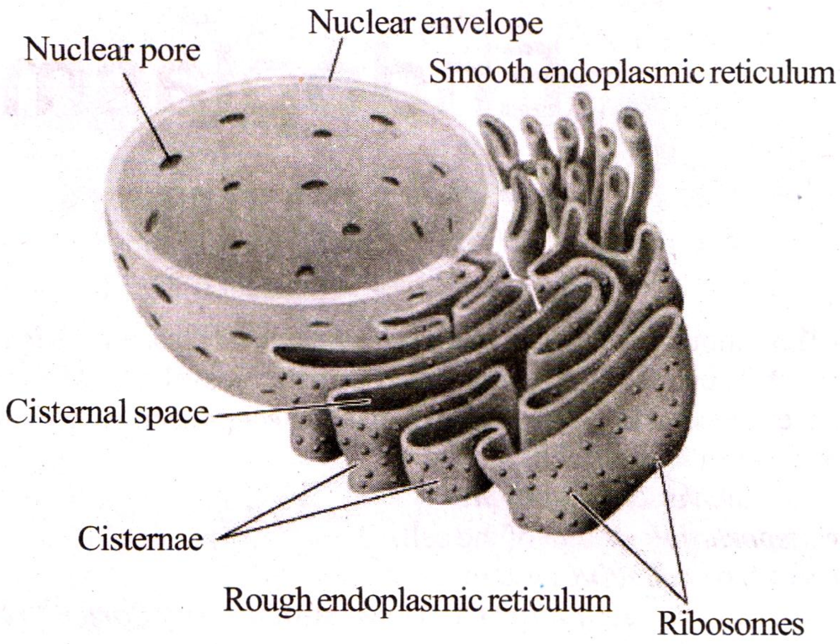


Fig. Endoplasmic reticulum

Cisternae

- These are long flattened, unbranched sac-like structures.
- They are arranged in parallel bundles.
- Their diameter is 40-50 m. micron.
- They have ribosomes on their surface.
- They are normally found in secretory cells

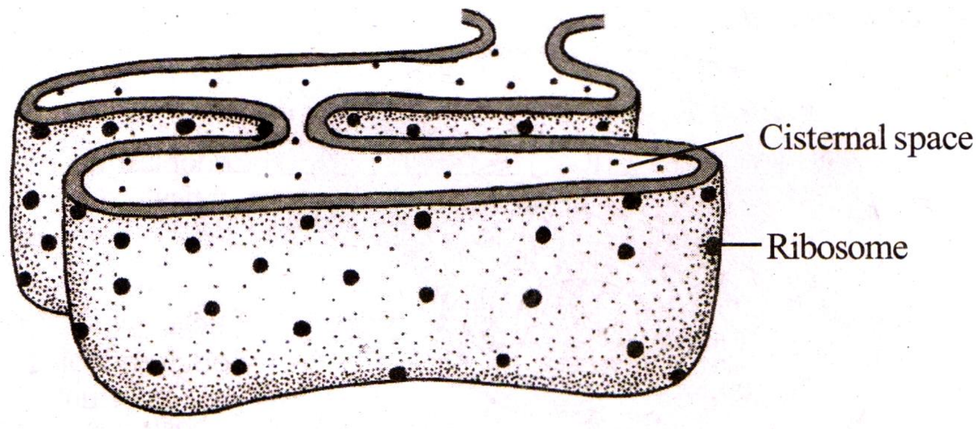


Fig. Cisternae of rough endoplasmic reticulum

Vesicles

- These are rounded or ovoidal structures having the diameter of 25-500 m. microns.
- They are found in abundance in pancreatic cells.
- They are found at the end of cisternae and tubules.
- Many vesicles are left free in the cytoplasm

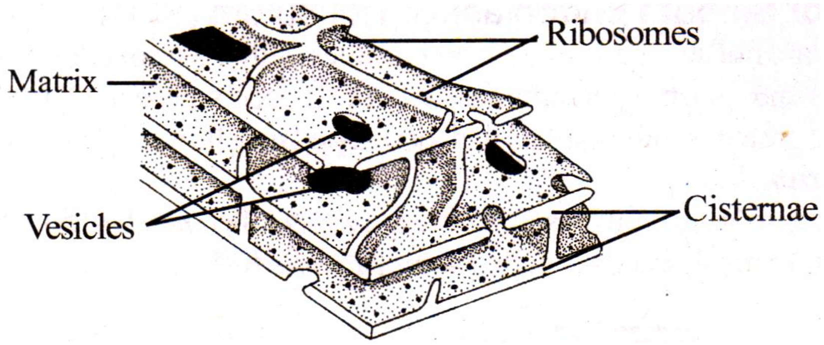


Fig. 3D – View of endoplasmic reticulum

Tubules

- These are smooth walled and highly branched tubular spaces having diverse forms.
- They have the diameter of 50-100 m. microns.
- They normally occur in non-secretory cells like striated muscle cells.
- They arise from the cisternae

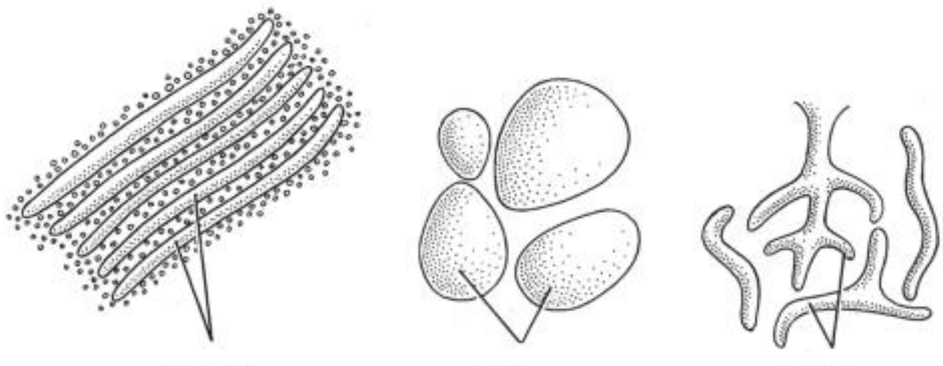


Fig. Components of endoplasmic reticulum

- ✓ Endoplasmic reticulum is classified into two types.
- ✓ They are:
  1. Granular or rough endoplasmic reticulum
  2. Agranular or smooth endoplasmic reticulum

1.Granular or rough endoplasmic reticulum

- In some endoplasmic reticulum, spherical granular structures called ribosomes are attached on the surface.
- This type of endoplasmic reticulum is called granular endoplasmic reticulum.
- The binding site of ribosome on the RER is called translocon.
- It occurs in almost all cells which are actively engaged in protein synthesis, such as liver cells, goblet cells, pancreatic cells and plasma cells.
- It is in the form of flattened sacs

2.Agranular or smooth endoplasmic reticulum

- Ribosomes are not attached with the membranes of this type of endoplasmic reticulum.
- So, the surface of this endoplasmic reticulum is smooth.
- It occurs especially in those cells which are almost inactive in protein synthesis.
- It is well developed in cells that synthesize steroid hormones.
- It is a system of tubules

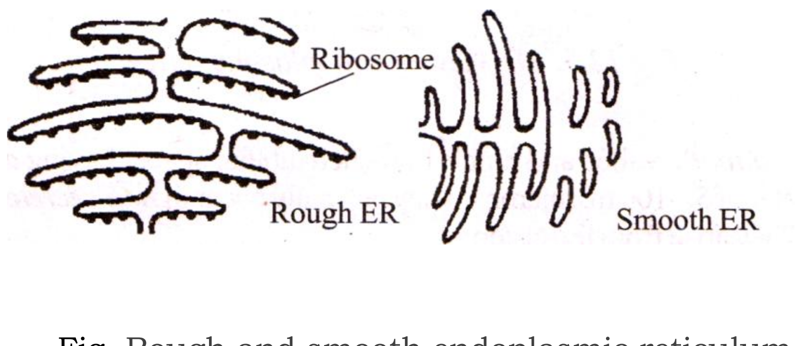


Fig. Rough and smooth endoplasmic reticulum

FUNCTIONS OF ENDOPLASMIC RETICULUM

- The endoplasmic reticulum acts as secretory, storage, circulatory and nervous system for the cell.
- It performs following important functions:

A. Common Functions of Granular and Agranular Endoplasmic Reticulum

1. **Mechanical support:**
   - ✓ The endoplasmic reticulum divides the fluid content of the cell into different compartments by which it gives mechanical support to the cell.
   - ✓ Hence it is known as the cytoskeleton of the cell

2. **Transport:**
   - ✓ Endoplasmic reticulum acts as a kind of circulatory system, involved in the import, export and intracellular circulation of various substances.
   - ✓ By this process, proteins, lipids, enzymes, etc. are transported to the various parts of the cell

3. **Protein synthesis:**
   - ✓ Ribosomes are protein factories. Amino acids are assembled on ribosomes to produce polypeptide chains.
   - ✓ The ribosomes attached to the endoplasmic reticulum are more efficient in protein synthesis than the free ribosomes lying in the cytoplasm.
   - ✓ The synthesized proteins are collected by the endoplasmic reticulum.
   - ✓ They are processed and transported to other parts of the cell by the endoplasmic reticulum

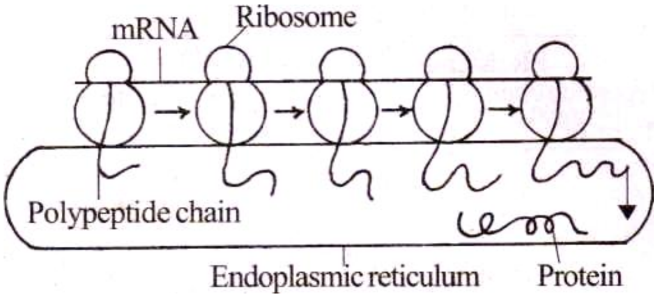


Fig.: Endoplasmic reticulum collects and transports the protein synthesized on ribosomes

4. **Synthesis of Cholesterol and Steroid Hormones:**

   ✓ Endoplasmic reticulum is the major site for the synthesis of cholesterol, the precursor for steroid hormones

5. **Detoxification:**

   ✓ Detoxification refers to the reduction of toxic properties of chemicals such as drugs and pollutants.

   ✓ Detoxification occurs in the endoplasmic reticulum of liver cells.

   ✓ Detoxification involves biochemical reactions by which harmful materials are converted into harmless substances suitable for excretion by the cell.

6. **Lipid synthesis:**

   ✓ ER synthesizes triglycerides and phospholipids. It also stores lipids

7. **Glycogenolysis:**

   ✓ The conversion of glycogen into glucose is called glycogenolysis.

   ✓ It takes place inside the ER.

   ✓ The ER contains an enzyme called glucose-6-phosphatase.

   ✓ It converts glucose-6-phosphate into glucose which is transported to the blood

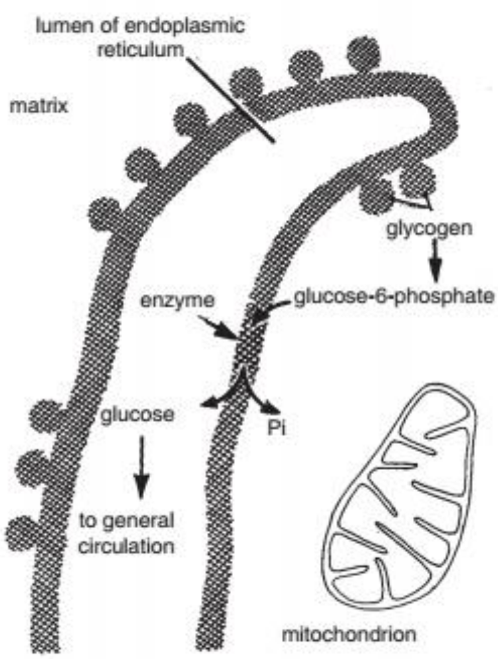


Fig.: Glycogenolysis with the consequent release of glucose.

B. Functions of Smooth Endoplasmic Reticulum.

- ✓ It synthesizes steroid hormones
- ✓ It synthesizes carbohydrates, lipids and cholesterol
- ✓ It synthesizes plasma membrane
- ✓ The SER of testis and ovary cells synthesizes male and female hormones
- ✓ In liver cells, SER detoxify drugs and harmful substances
- ✓ In the muscle cells, it assists in the contraction of muscle cells
- ✓ The SER of muscle cells stores calcium ions

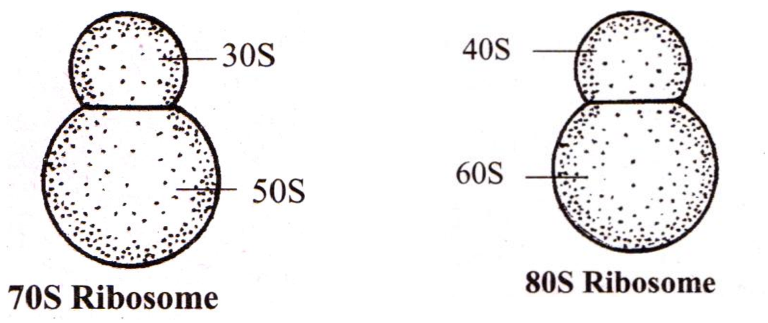
C. Functions of Rough Endoplasmic Reticulum

- ✓ Ribosome of RER is the site of protein synthesis
- ✓ RER produces secretory products
- ✓ RER buds off vesicles which transport the secretory products
- ✓ The RER of plasma cells (WBC) secretes antibodies
- ✓ The RER of pancreatic cells secretes insulin
- ✓ In the lumen, proteins are linked with sugars to form glycoproteins. This process is called glycosylation

Ultrastructure and functions of

RIBOSOMES

- Ribosomes were first observed by Claude in 1941 and named them as microsomes.
- Palade in 1955 named them as ribosomes
- Ramakrishnan, Steitz and Ada E. Yonath described the structure and functions of ribosomes and for their work they were given Nobel Prize in 2009
- Ribosomes are found in all the living cells which synthesize protein.
- They are usually located on the membranes of the endoplasmic reticulum. Some ribosomes remain scattered in the cytoplasm.



STRUCTURE OF RIBOSOMES

- Ribosomes are protein factories
- Ribosomes are spherical in shape.
- The ribosomes of prokaryotes are smaller in size and eukaryotes are larger in size
- In prokaryotes, they are 150A° and in eukaryotes, they are 250A° in diameter

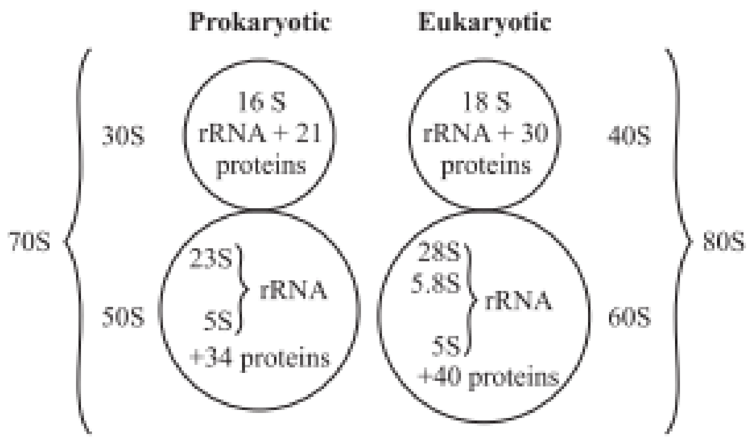


Fig. Various components of prokaryotic (70S) and eukaryotic (80S) ribosomal subunits.

- Each ribosome consists of two sub-units, namely a large sub-unit and a small sub-unit

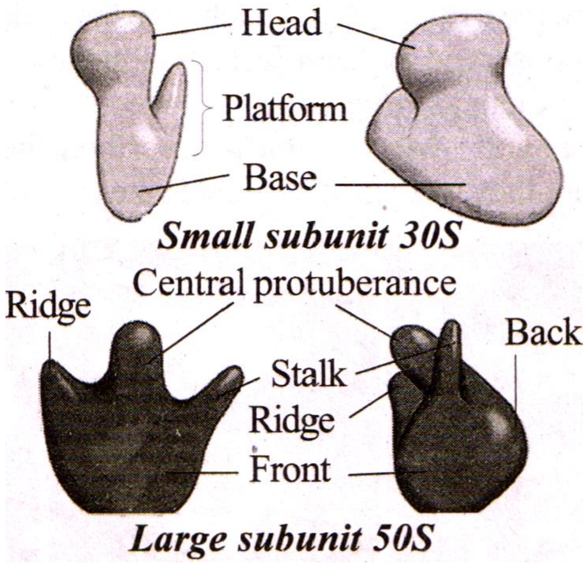
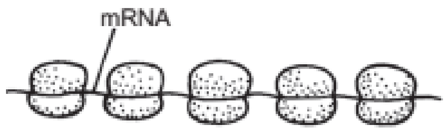


Fig. prokaryotic ribosomes (70S)

- The sub-units occur separately in the cytoplasm. They join together to form ribosomes only at the time of protein synthesis
- Generally 5 or more ribosomes line up and join an mRNA chain. Such a string of ribosomes is called polyribosome or polysome



polyribosome

- The small sub-unit holds the mRNA during protein synthesis
- The ribosome has 3 binding sites, namely A-site, P-site and E site.
- The A-site carries a tRNA containing activated amino acid.
- The P-site carries a tRNA containing polypeptide chain.
- The E site is the exit site from where the deacylated tRNA is released into the cytosol
- The eukaryotic ribosome has only two sites, namely A site and P site, the E-site being absent.

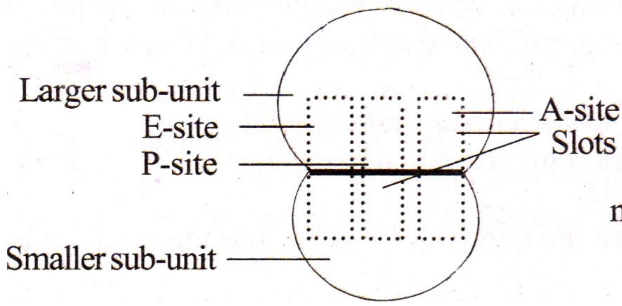


Fig. A ribosome showing slots

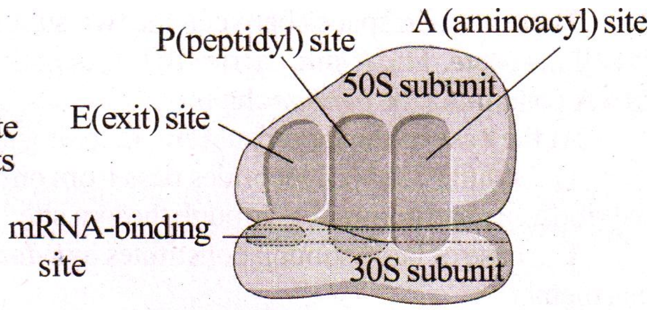


Fig. Ribosomes with three sites

- According to the size and sedimentation co-efficient, 2 types of ribosomes have been reported.
- They are 70S ribosomes and 80S ribosomes.
- 70S is found in prokaryotes. It is made up of two subunits namely, 30S and 50S
- 80S is found in Eukaryotes. It is made up of 40S and 60S
- The small subunit is somewhat flat and discoid.
- Its lower surface is slightly convex but its upper surface is slightly concave.
- The small subunit is an asymmetrical structure.
- There is a cleft on the upper surface, which divides the subunit into a head and a base

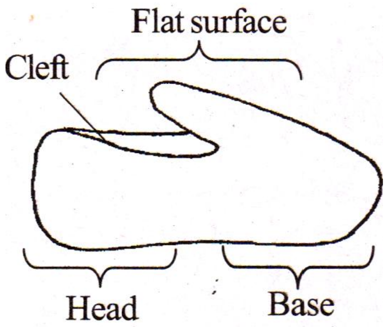


Fig. Small subunit of ribosome

- The large subunit is a spherical structure with three convex sides and a concave bottom.
- Main body of this subunit is called base.
- There is a large protuberance on one side. On either side of the protuberance there is a depression.
- It makes a clear stalk on one side of the protuberance
- The concave surface of small subunit is bound to the bottom of the large subunit. Protuberance of the large subunit is aligned with the head of the small subunit

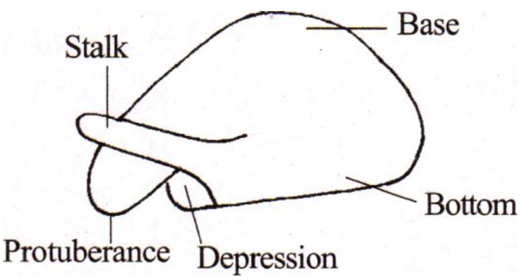


Fig. Large subunit of ribosome

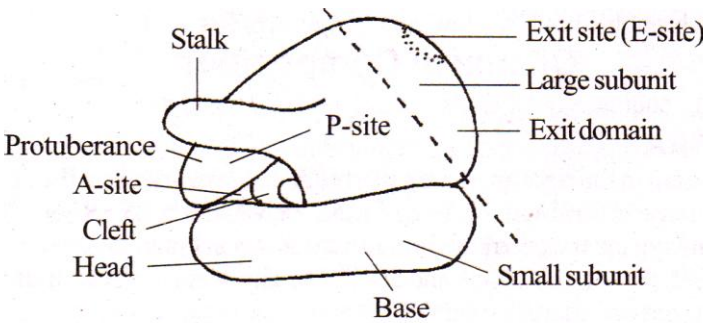


Fig. Structure of ribosome

FUNCTIONS OF RIBOSOMES

- **Protein Synthesis**
  - ✓ Ribosome plays an important role in protein synthesis.
  - ✓ It is the assembly shop or engine where amino acids are linked to produce proteins.
  - ✓ During protein synthesis, die two sub- units join together on the mRNA.
  - ✓ Like this, many ribosomes are attached to the mRNA to form a polyribosome.
  - ✓ The ribosomes contain binding sites for the attachment of tRNA containing activated amino acid and tRNA containing peptide chain.
  - ✓ The ribosomes move on the mRNA.
  - ✓ As they move along the triplet codon, the mRNA is translated and the peptide chain is elongated by the addition of correct amino acids one-by-one

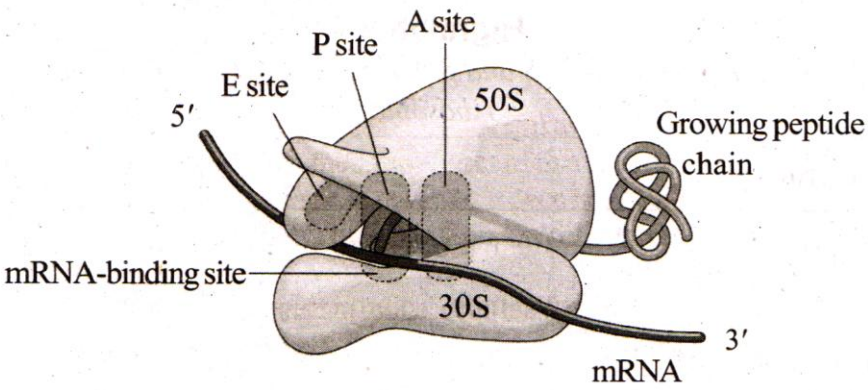


Fig. Protein synthesis

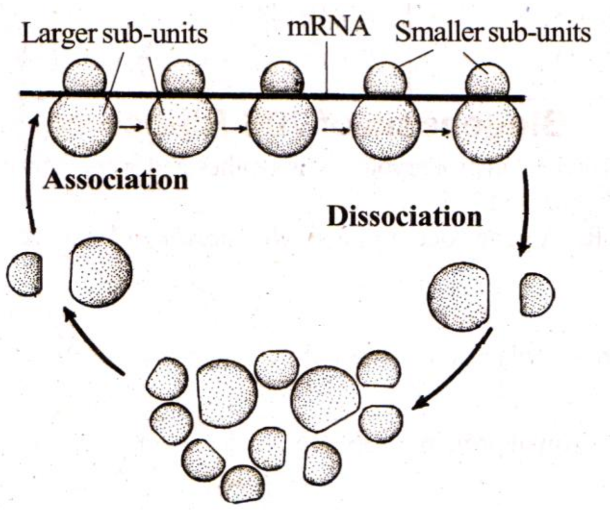


Fig. Polyribosomes in protein synthesis

Ultrastructure and functions of

MITOCHONDRIA

- The mitochondria are thread-like or granular cytoplasmic organelles (Gr.mito = thread, chondrion = granule).
- They contain many enzymes and coenzymes which are responsible for energy metabolism
- They are described as the power houses of cells.
- The mitochondria play main roles in cellular respiration and energy production
- The mitochondria were first observed by Flemming and Kolliker in 1882.
- Mitochondria are found both in plant and animal cells. But they are absent from prokaryotes.

  The mitochondria may be filamentous or granular in shape.
- The shape of mitochondria may change from one cell to another depending upon the physiological conditions of the cell.

  They may be rod-shaped, club-shaped, ring-shaped, rounded or vesicular
- The size of the mitochondria is highly variable. In most cells, their length varies from 3 to 10 microns and their width from 0.2 to 1.0 micron.
- The smallest mitochondrion is seen in yeast.
- The largest mitochondria are found in the oocytes of amphibian
- The number is particularly related to the functional state of the cell.
- If the metabolic activity is high, the number of mitochondria is also high.
- A small number indicates cells of low metabolic activity.
- Thus, they are found to be more abundant in liver and kidney cells.
- In most cells, the mitochondria are distributed uniformly throughout the cytoplasm.
- But in some cases, they are aggregated around the nucleus.
- The mitochondria are covered by two membranes, namely an outer and an inner mitochondrial membranes, each measuring about 60A in thickness.
- The two membranes are separated by a space of 80 to lOO Å.
- The space between the outer and inner mitochondrial membranes is called outer chamber or perimitochondrial space.
- This chamber is filled with a fluid of low viscosity and density

- The central space of the mitochondria is called the inner chamber.
- The inner chamber is filled with mitochondrial matrix.
- The matrix contains 70S ribosomes and mitochondrial DNA.

  The inner mitochondrial membrane produces finger-like projections known as cristae into the inner chamber
- The mitochondrial membrane contains small particles called elementary particles or F particles or electron transport particles (ETP).
- The particles of the outer membrane are stalkless
- ETP of the inner membrane are stalked. Each stalked particle consists of a stalk and a head.
- They are regularly placed at a distance of 100A
- Cristae are the finger-like projections found inside the mitochondria.
- They develop as in pushings projecting into the central space from the inner membrane.
- They form incomplete septa. They are present inside the inner chamber of mitochondria
- The cristae are covered with small particles called elementary particles or F1 particles.

  Each F1 particle has a base, a stalk and a head. The head is 80-100A in diameter and the stalk is about 30-40A in diameter
- The cristae are variously arranged. In frog, they are longitudinal and the cristae are arranged parallel to the long axis of mitochondria. In the adrenal cortex, the cristae are transverse as they are found perpendicular to the long axis. They are network-like in the WBC of man.

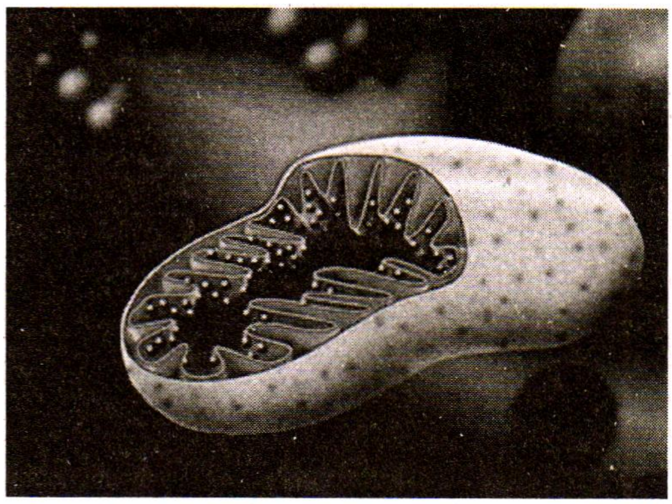


Figure *: Mitochondria.*

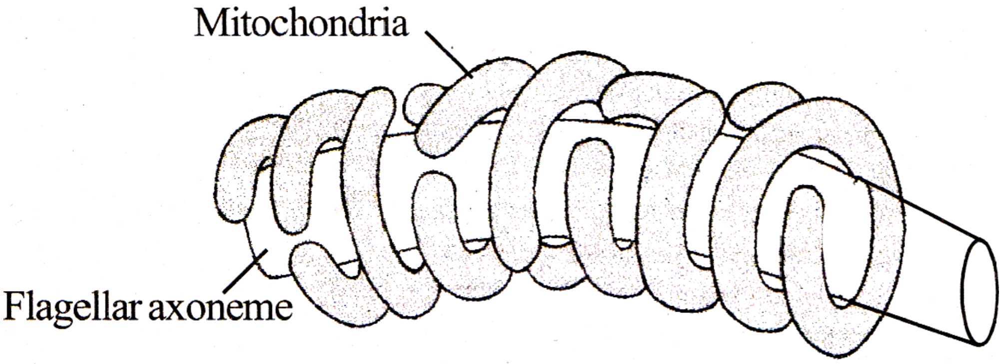


Figure: *Mitochondria in sperm tail.*

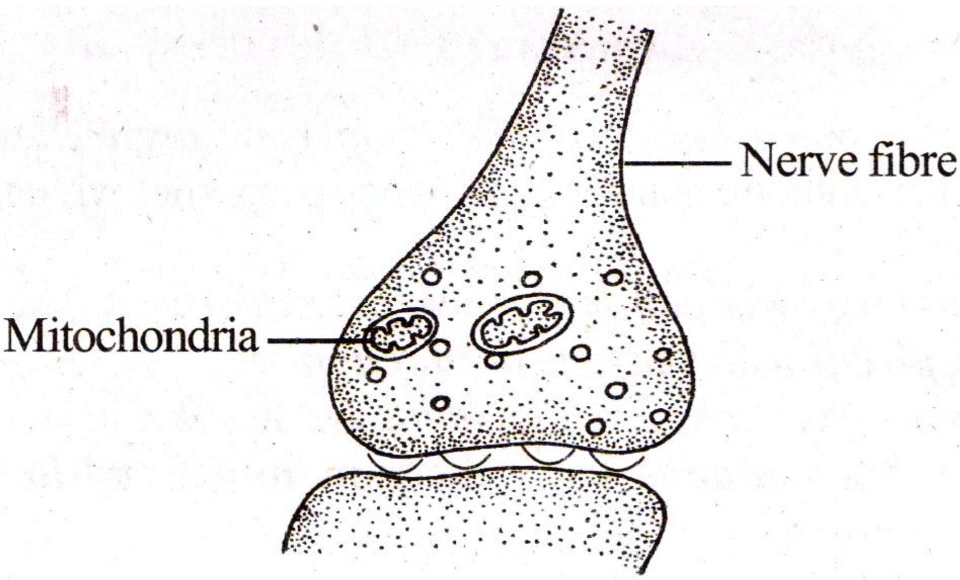


Figure *: Mitochondria(in neurons).*

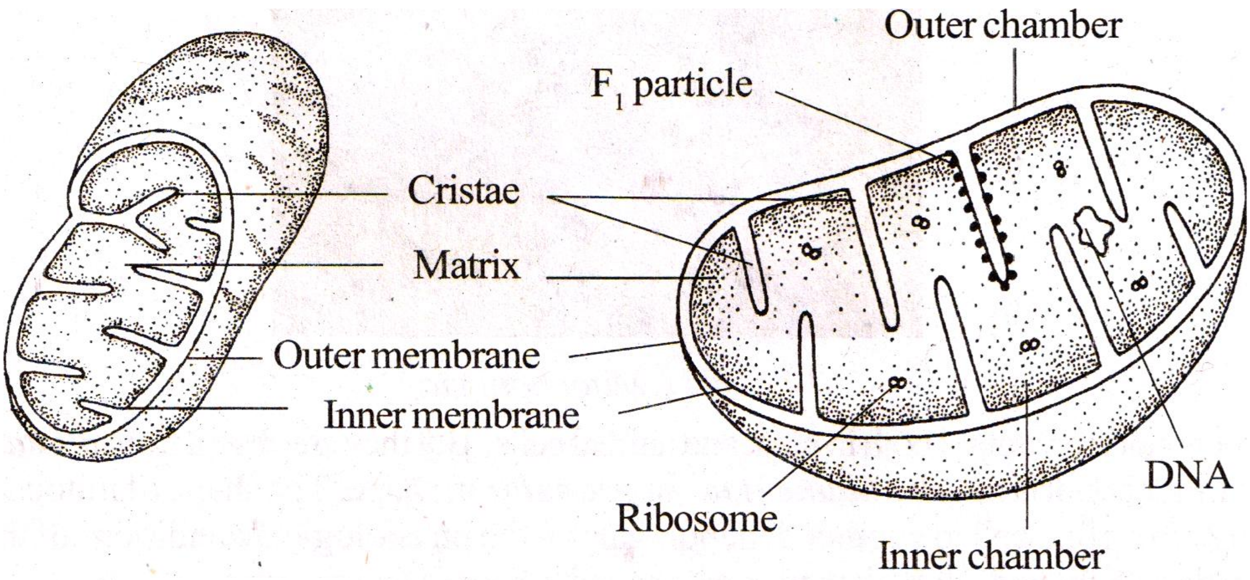


Figure *: Structure of a typical mitochondrion.*

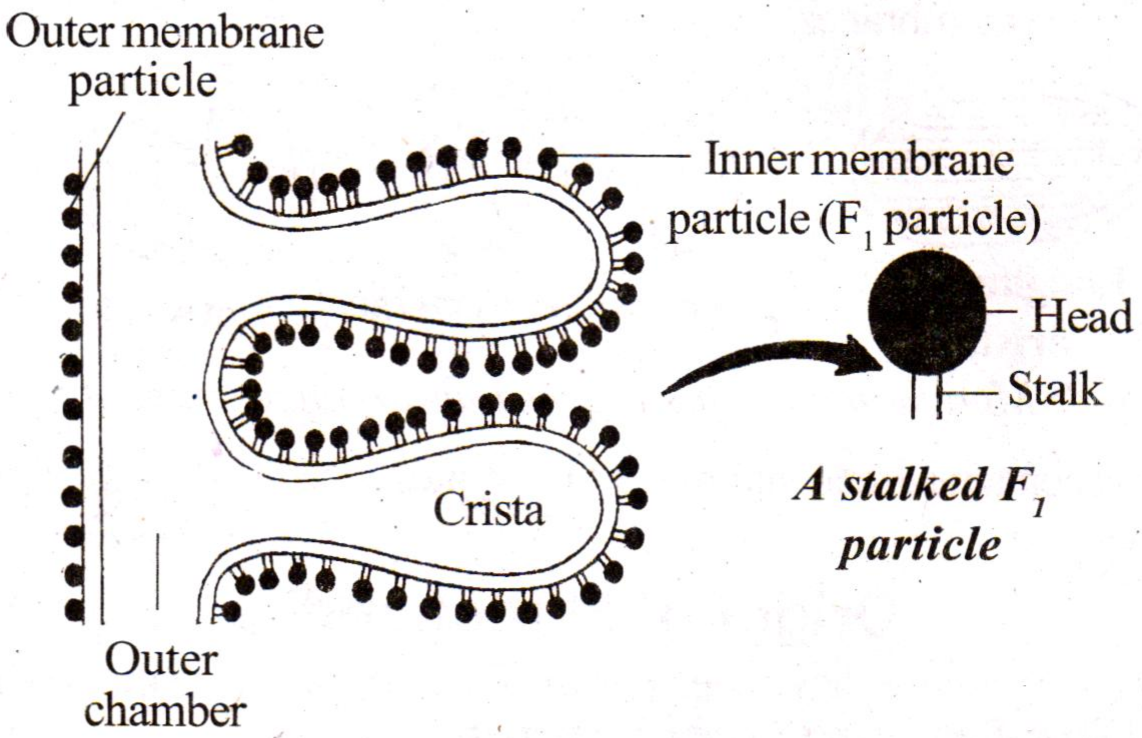


Figure : *Cristae showing F_1 particles.*

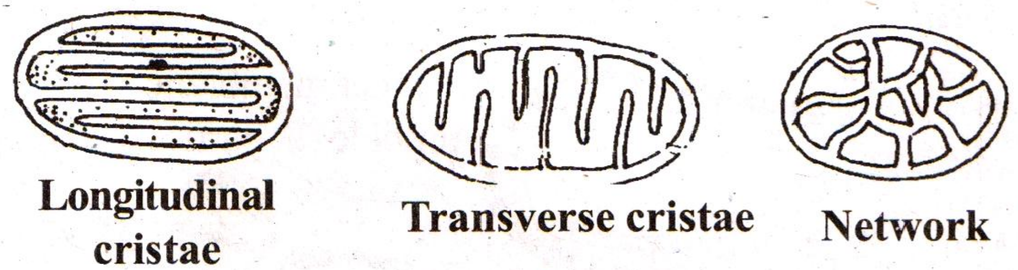


Figure : *Mitochondria showing various arrangements of cristae.*

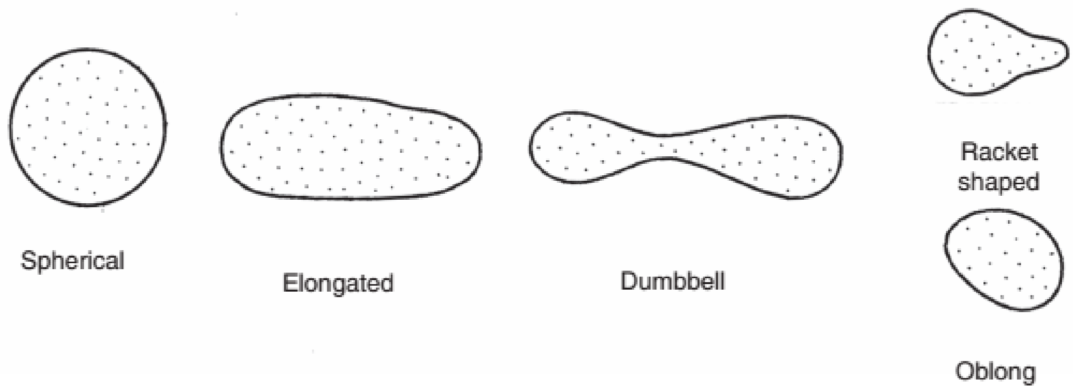


Figure: Different shapes of mitochondria

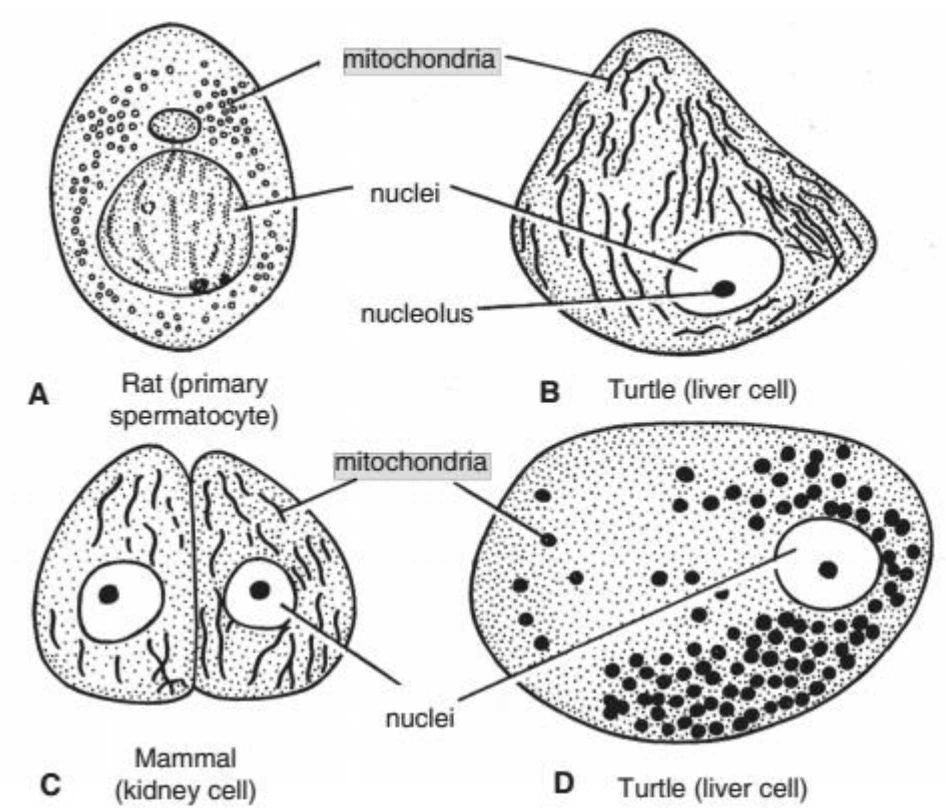


Figure: Mitochondria of different type of animal cells

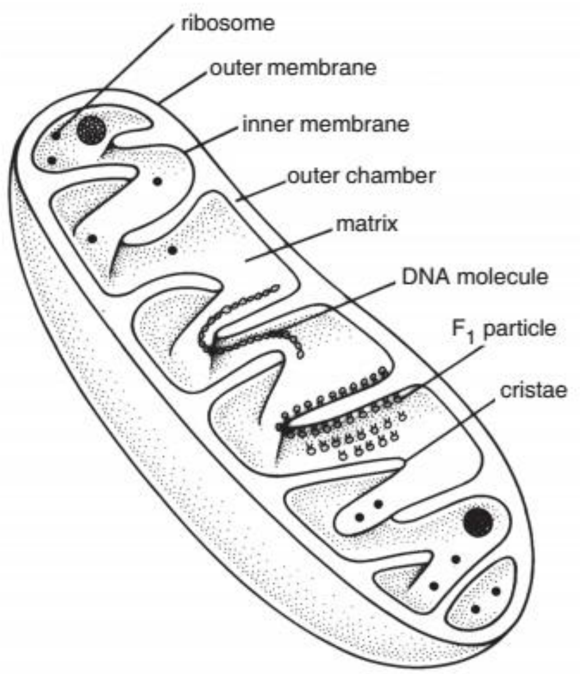


Figure: Mitochondrion showing internal structure

Functions of Mitochondria

Mitochondria perform the following functions:

a. Thermogenesis
b. Protein synthesis
c. Synthesis of steroid hormones
d. Urea cycle
e. Calcium accumulation
f. Energy supply
g. Cellular respiration

Thermogenesis

- In young mammals and hibernating mammals such as bats, there is a special tissue in the chest region.
- It is called brown fat.
- It consists of extensive vascularization and numerous mitochondria.
- It functions as an automatic furnace and generates enormous heat.
- Here mitochondria are concerned with the release of heat energy rather than synthesizing ATP
- Protein synthesis
- Mitochondria contain DNA. About 5 to 10% of proteins of mitochondria are synthesized by the mitochondrial genes.
- Mitochondria synthesize sub-units of ATPase, portions of reductase and three sub-units of cytochrome oxidase

1. Synthesis of Steroid Hormones

The early steps in the conversion of cholesterol to steroid hormones in the adrenal cortex, are catalyzed by mitochondrial enzymes

2. Urea Cycle

In urea cycle, urea is synthesized. The first step of the urea cycle, that is the conversion of ornithine to citrulline occurs in the mitochondria

3. Calcium Accumulation

One of the important functions of mitochondria is the accumulation of cations, such as calcium.

Calcium can be accumulated in mitochondria several hundred times than the normal values.
Phosphate can also enter along with calcium. This process usually occurs in the osteoblast during the formation of bone

4. **Energy Supply**
    - Mitochondria are the energy plants of the cell.
    - Mitochondria synthesize the energy rich compound, ATP.
    - It is stored inside the mitochondria.
    - When a site is in need of energy, mitochondria get collected around the site. The mitochondrial membrane contracts and squeezes out ATPs
    - Mitochondria are found in high concentrations at the sites of active transport where large amount of energy is needed. This happens in kidney cells

5. **Cell Respiration**
    - Mitochondria are the respiratory centres of the cell.
    - They bring about the oxidation of the various food stuffs such as carbohydrates, fats and proteins.
    - During oxidation, the food stuffs are degraded to CO_2, and water with the release of energy.
    - This energy is utilized by the mitochondria for the synthesis of energy rich compound called ATP.
    - As mitochondrion synthesizes the energy rich compounds, it is called the power house of the cell

   The cell respiration involves the following steps:
    a. Glycolysis
    b. Oxidative decarboxylation
    c. Krebs cycle
    d. Electron transport system
    e. Oxidative phosphorylation

Ultrastructure and functions of

LYSOSOMES

INTRODUCTION

- The lysosomes (Gr., lyso = digestive + soma = body) are tiny membrane bound vesicles involved in intracellular digestion.
- They contain a variety of hydrolytic enzymes that remain active under acidic conditions.
- They were discovered by deDuve in 1955.
- A lysosome is a lytic body. It is capable of lysis.
- It can destroy a cell in which it releases its enzymes. Hence, it is often called suicidal bag.

STRUCTURE

- Lysosomes occur in most animal cells and in a few plant cells. They are most abundant in cells which are related with enzymatic reactions such as liver cells, pancreatic cells, kidney cells, spleen cells, leucocytes, etc.

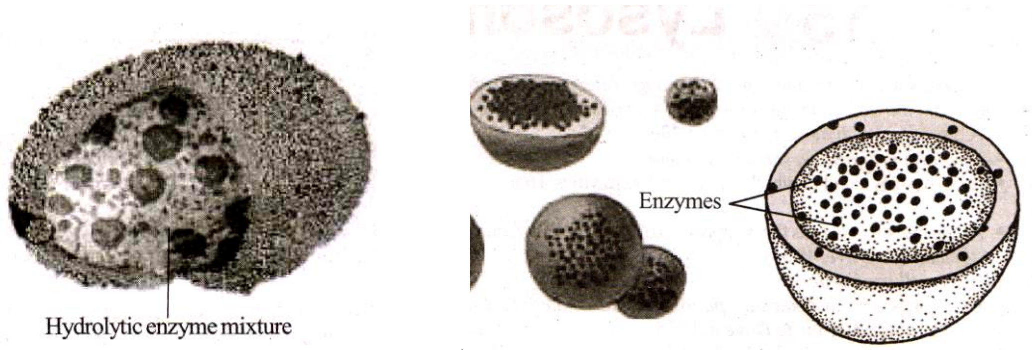


Fig. Lysosome

- Lysosomes are usually spherical in shape
- The size of the lysosomes usually ranges from 0.2 micron to 0.8 micron in diameter, but may be exceptionally large as 8 microns in mammalian kidney cells and leucocytes.
- Lysosomes are spherical dense bodies filled with large number of dense granules having hydrolytic enzymes and acid phosphatases.
- The lysosomes are bounded by a single layered membrane in contrast to the double- layered membranes of other organelles.
- It is a membrane like that of plasma membrane. It is made up of proteins and lipids. Proteins in the lysosome membrane are glycosylated with sugar residues.
- The interior of some lysosomes are uniformly solid while others have very dense outer zone and a less dense inner zone.
- The interior of the lysosome is acidic with a pH of 4.8, but the pH of the surrounding cytosol is 7.2.
- The low pH is maintained by pumping protons (H^+) from the cytosol.

KINDS OF LYSOSOMES (POLYMORPHISM IN LYSOSOMES)

- Lysosomes are extremely dynamic organelles, exhibiting polymorphism in their morphology.
- Following four types of lysosomes have been recognized in different types of cells or at different times in the same cell.
- Of these, only the first is the primary lysosome, the other three have been grouped together as secondary lysosomes.

1.Primary Lysosomes

- These are also called storage granules, protolysosomes or virgin lysosomes.
- Primary lysosomes are newly formed organelles bounded by a single membrane and typically having a diameter of 100 nm.
- They contain the degradative enzymes which have not participated in any digestive process.
- Each primary lysosome contains one type of enzyme or another and it is only in the secondary lysosome that the full complement of acid hydrolases is present.

2.Heterophagosomes

- They are also called heterophagic vacuoles, heterolysosomes or phagolysosomes.
- Heterophagosomes are formed by the fusion of primary lysosomes with cytoplasmic vacuoles containing extracellular substances brought into the cell by any of a variety of endocytic processes (e.g., pinocytosis or phagocytosis).
- The digestion of engulfed substances takes place by the enzymatic activities of the hydrolytic enzymes of the secondary lysosomes.
- The digested material has low molecular weight and readily passess through the membrane of the lysosomes to become the part of the matrix.

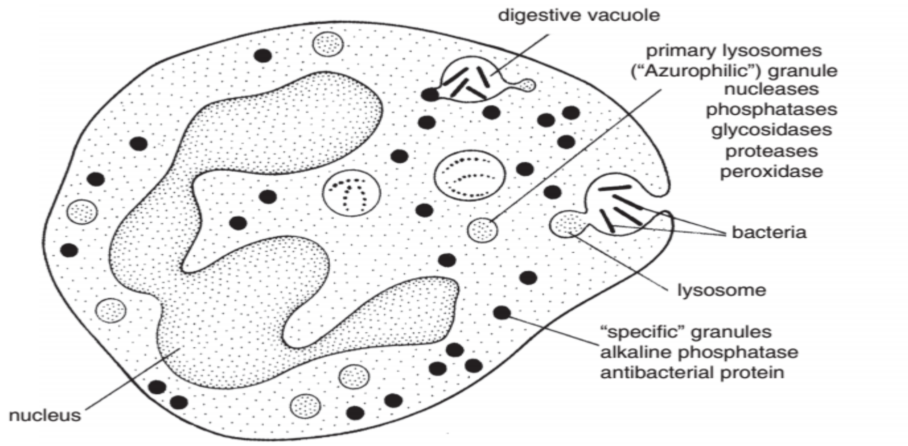


Fig. Diagram of a white blood cell (neutrophil) ingesting bacteria. Two types of granules fuse with the phagocytotic vacuoles and contribute digestive enzymes and other components.

3. Autophagosomes

- They are also called autophagic vacuole, cytolysosomes or autolysosomes.
- Primary lysosomes are able to digest intracellular structures including mitochondria, ribosomes, peroxisomes and glycogen granules.
- Such autodigestion (called autophagy) of cellular organelles is a normal event during cell growth and repair and is especially prevalent in differentiating and dedifferentiating tissues (e.g., cells undergoing programmed death during metamorphosis or regeneration) and tissue under stress.

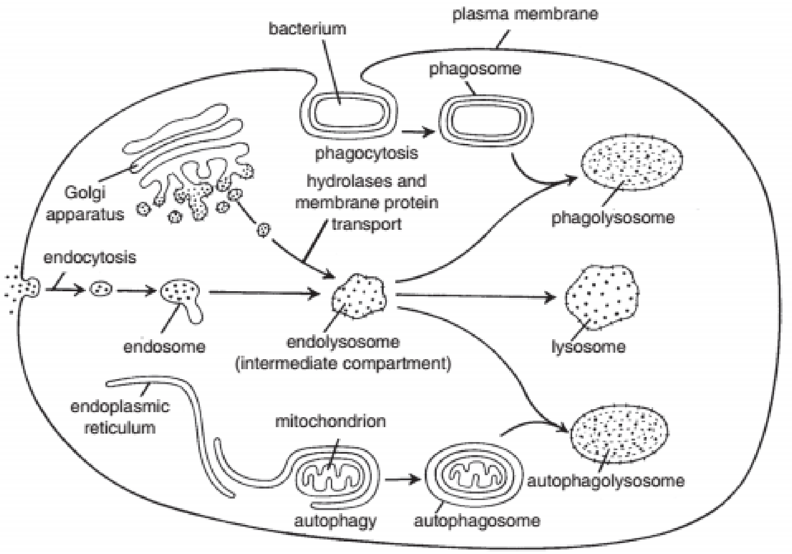


Fig. Origin of three types of lysosomes : phagolysosome, lysosome (the classical secondary lysosome) and autophagolysosome. Transport vesicles (the classical primary lysosomes) originate from trans Golgi network to fuse with endolysosome which contains already endocytosed materials for digestion.

4.Residual Bodies

- They are also called telolysosomes or dense bodies.
- Residual bodies are formed if the digestion inside the food vacuole is incomplete.
- Incomplete digestion may be due to absence of some lysosomal enzymes.
- The undigested food is present in the digestive vacuole as the residues and may take the form of whorls of membranes, grains, amorphous masses, ferritin-like or myelin fibres

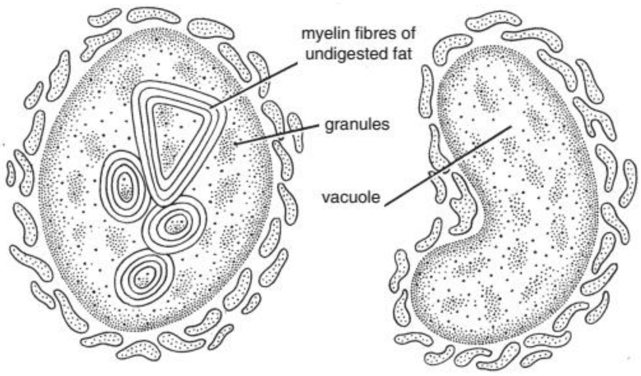


Fig. Lysosomes of the kidney cells of rat, showing the presence of residues.

Heterophagy

- *Heterophagy is* the lysosomal digestion of foreign materials. *It is an intracellular digestion.*
- In heterophagy, the cells digest the foreign or extracellular food materials.
- These food materials are taken into the cells by endocytosis such as *phagocytosis* or *pinocytosis.*
- The food materials are enclosed in vesicles called *phagosomes* or *pinosomes.*
- These vesicles move towards lysosomes and fuse with the primary lysosome to form a digestive vacuole called *secondary lysosome.*
- The vacuole now moves to the plasma membrane.
- The enzymes of lysosomes digest the food materials in the digestive vacuole.
- The digested food materials diffuse into the cytoplasm through membrane of digestive vacuole.
- The digestive vacuole containing waste materials is called residual body. The waste materials are expelled out by exocytosis.
- This vacuole fuses with the plasma membrane so that its content is discharged out.

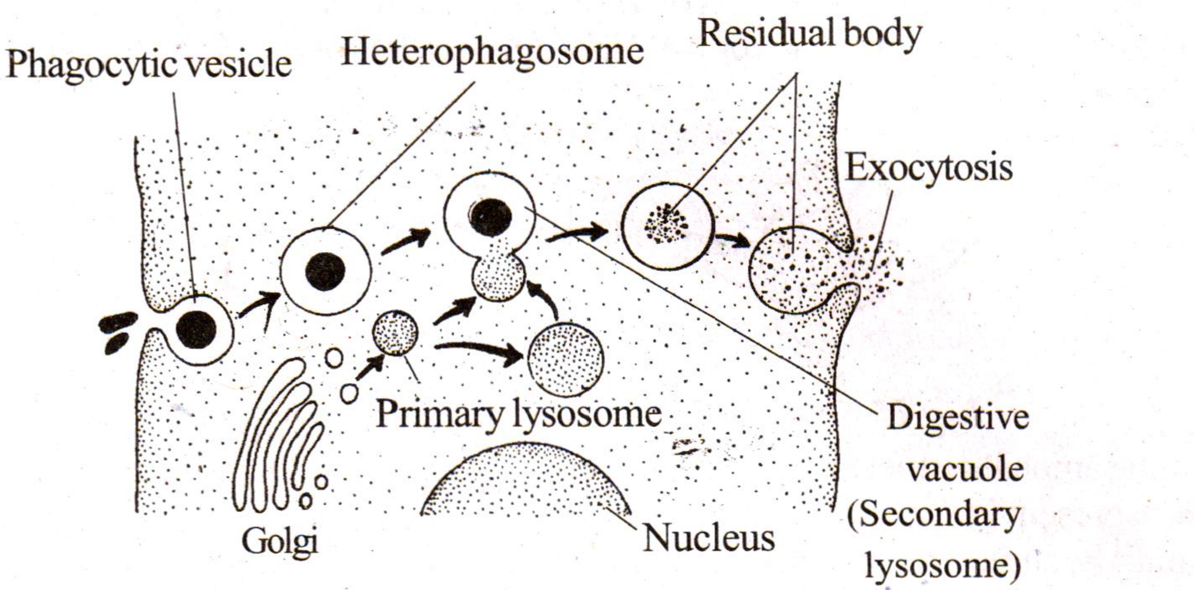


Fig. Heterophagy

Autophagy

- Autophagy refers to the lysosomal digestion of own cell components. (Auto = self; phagy = eating). It is an intracellular digestion
- In autophagy, the cell organelles, worn out cells, dead cells, cell debris and stored food materials are digested by the lysosomes
- In autophagy, the organelle to be digested, is enclosed by a membrane called isolation membrane. The isolation membrane is derived from endoplasmic reticulum or Golgi body
- The vesicle formed in this way is called an isolation body. The isolation body fuses with the lysosome to form an autophagic vesicle. The digested particles diffuse into the cytoplasm and are utilized by the cell for the metabolic activities
- Menstruation is caused by the autophagy of uterine epithelium

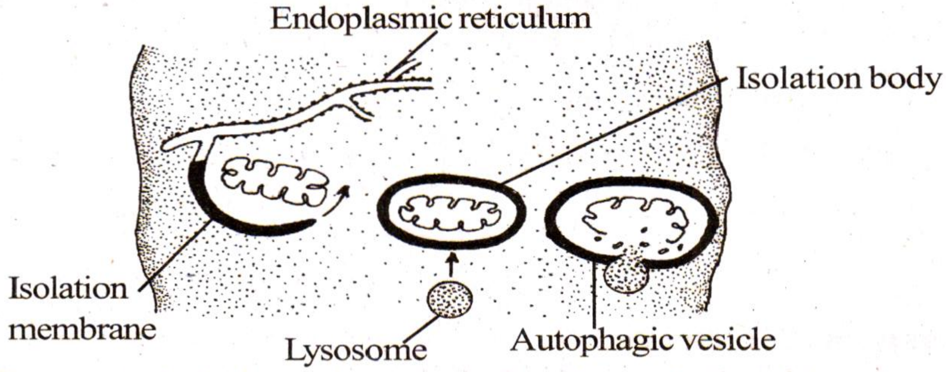


Fig. : Autophagy. Lysosome digests a mitochondrion.

Autolysis

- Autolysis refers to the digestion of own cells by the lysosomes. Auto means 'self and lysis means 'digestion '. It is self digestion. It is an intracellular digestion
- In autolysis, the lysosome digests its own cell. Hence autolysis is also called cellular autophagy
- In this process, the lysosome ruptures inside its cell and the released enzymes digest and degrade the cell. As lysosome kills its own cell, it is called suicidal bag
- Autolysis occurs during amphibian metamorphosis, insect metamorphosis, etc
- During amphibian metamorphosis, the cells in the tail, gills, etc. are digested by the enzyme cathepsin, present in the lysosome

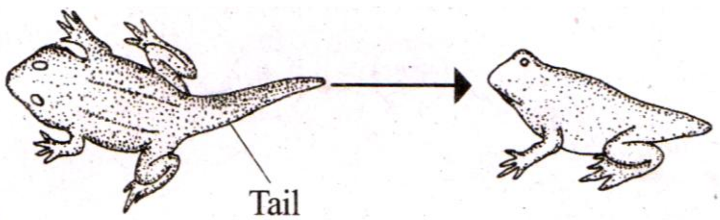


Fig. : Regression of tail in tadpole by autolysis.

Extracellular Digestion

- Digestion of materials outside the cell is called extracellular digestion.
- In certain occasions, lysosomes release enzymes outside the cell by exocytosis and bring about digestion.
- During fertilization, the sperm releases lytic enzymes of the acrosome on the surface of egg membrane. The lytic enzymes dissolve the egg membranes. This helps the sperm penetration.
- Extracellular digestion occurs during bone erosion. The osteoclasts are rich in lysosomes.
- In the area of erosion, the lysosomes release enzymes outside the cell and bring about extracellular digestion of bone.

Fertilization

- During fertilization, the acrosome of sperm ruptures and releases enzymes such as hyaluronidase, protease, etc.
- These enzymes dissolve the egg membrane and make way for the entry of sperm into the egg
- These enzymes also activate the egg by the breaking down of cortical granules

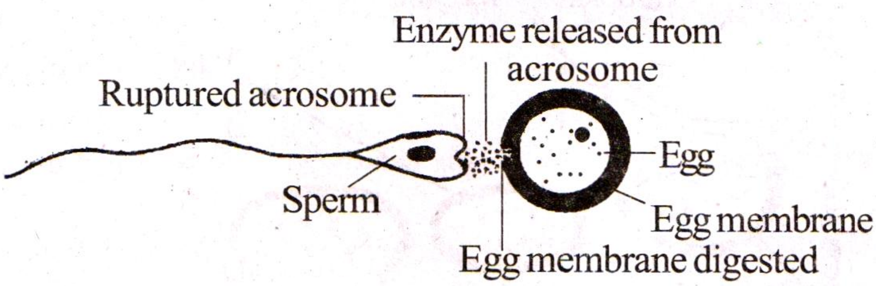


Fig. : Role of acrosome in fertilization.

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