CELL AND MOLECULAR BIOLOGY
UNIT II
MITOCHONDRIA

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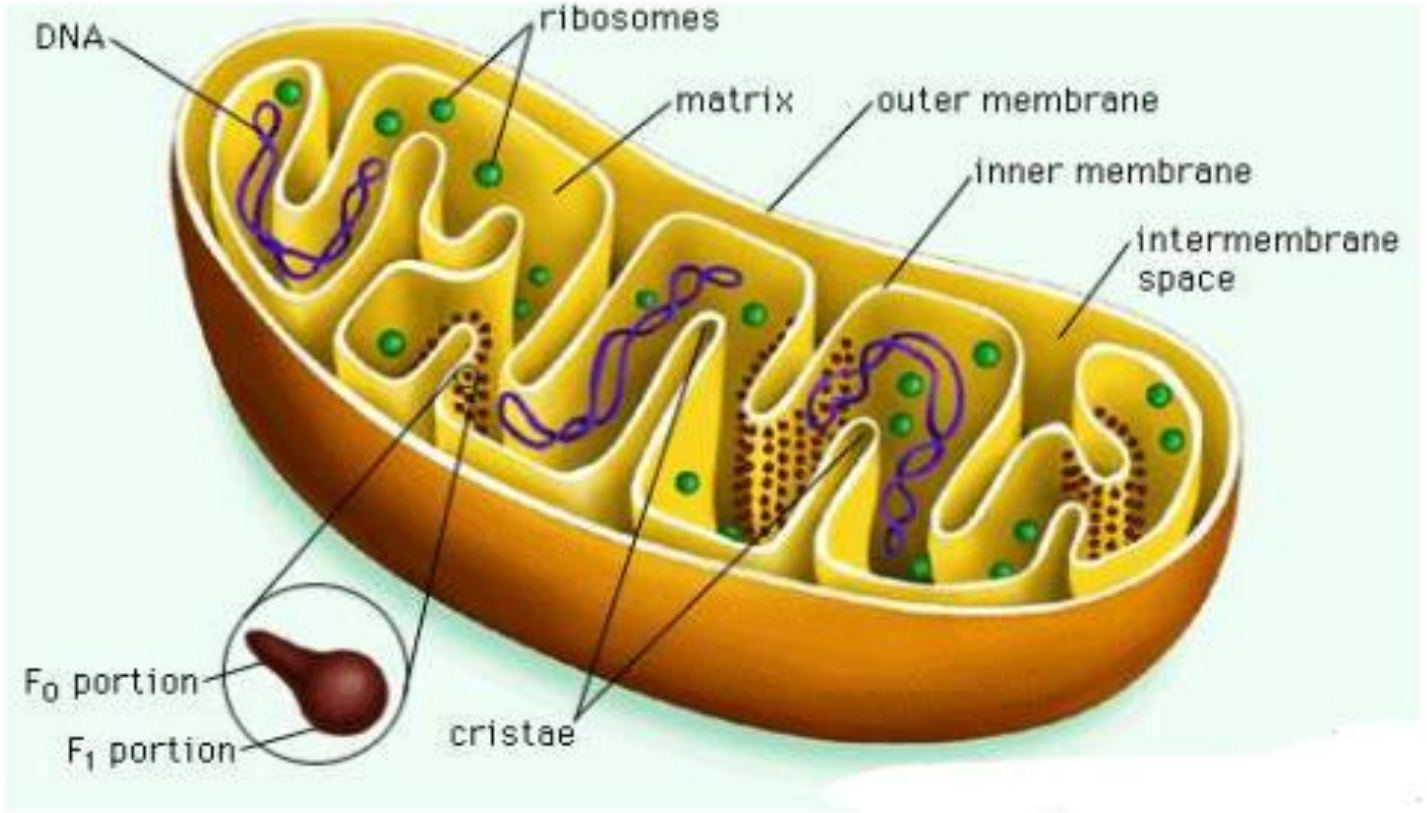


Mitochondria

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 plants*** or ***power houses*** of cells.

The mitochondria were first observed by ***Flemming*** and ***Kolliker*** in 1882. These organelles were first called bioblasts by ***Altmann.*** Later the term ***mitochondria*** was introduced by ***Benda*** in 1898.

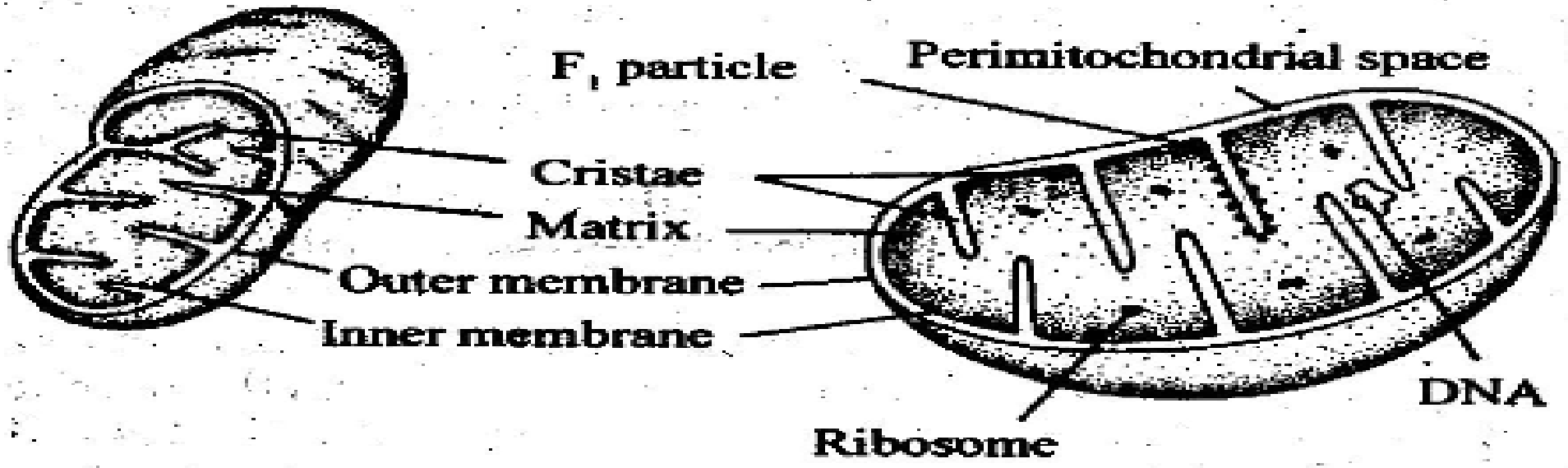
Mitochondria are found both in plant and animal cells. But they are absent from ***prokaryotes.***

The mitochondria may be ***filamentous*** or ***granular*** in shape. The shape of mitochondria may change from one 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 amphibia.

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. The giant Amoeba ***(Chaos chaos)*** contains 50,000 mitochondria whereas the egg of sea urchin contains 1,40,000 - 1,50,000 mitochondria.

The mitochondria are covered by two unit 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 100A°. The space between the outer and inner mitochondrial membranes is called ***outer chamber.*** 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 may contain filamentous materials or dense granules. The inner mitochondrial membrane gives out certain finger-like projections known as ***cristae.***



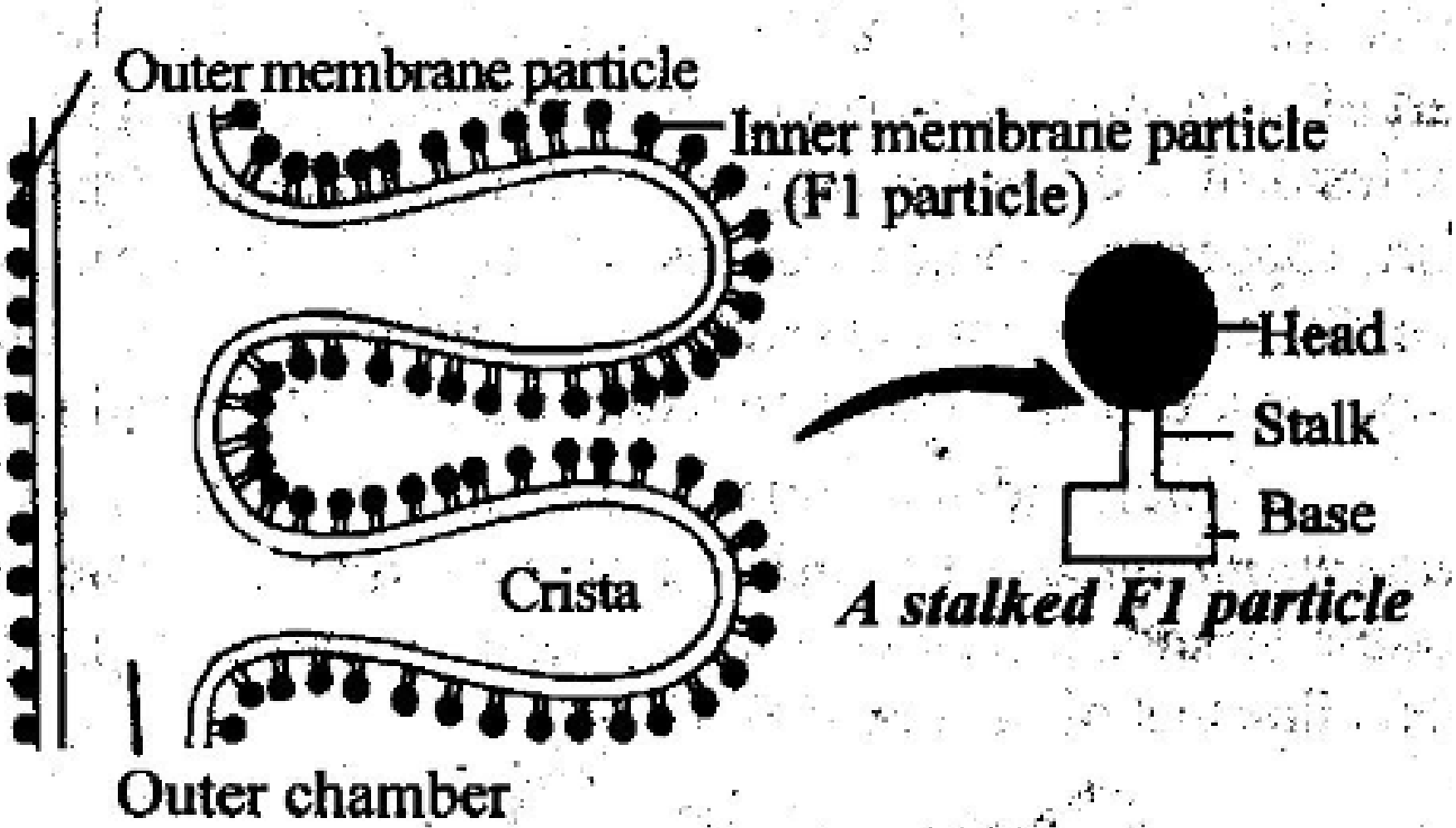
Structure of a typical mitochondrion.

The mitochondrial membrane contains small particles called ***elementary particles*** or ***F1 particles*** or ***oxysomes*** or ***electron transport particles*** (ETP). The particle of the outer membrane are stalkless.

The particles of the inner membrane are stalked. Each stalked particle consists of a ***base piece,*** a ***stem*** 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 inpushings 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.***



Cristae showing F1 particles.

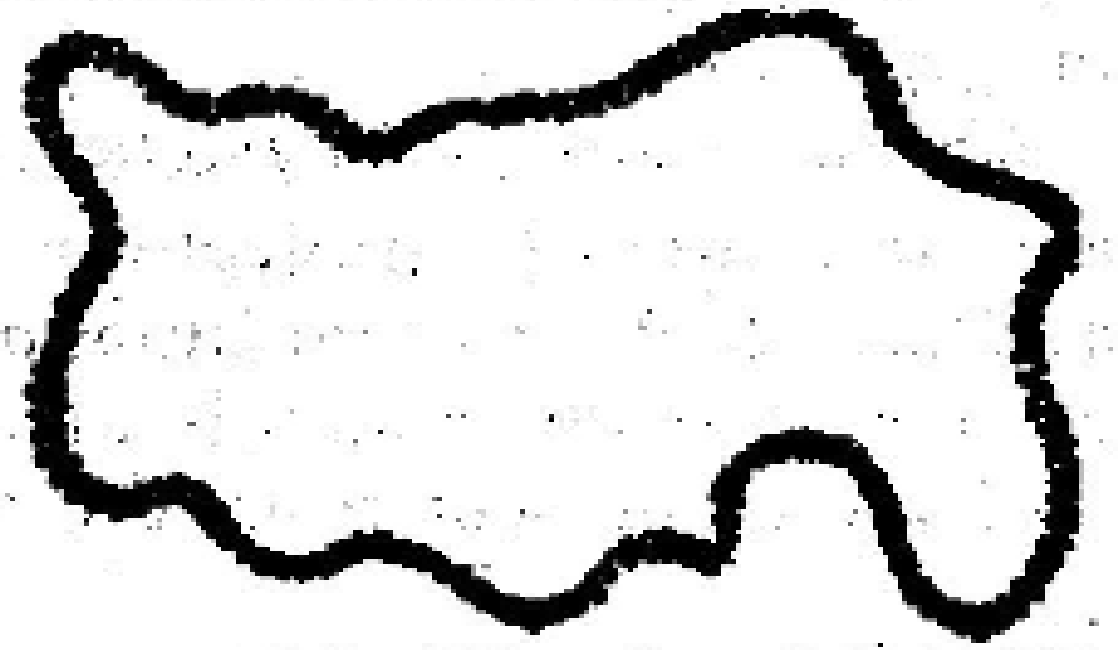
Longitudinal cristae ***Transverse cristae*** ***Network***

Mitochondria showing various arrangements of cristae.

The cristae are variously arranged. In frogs , 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 may be ***tubular*** as in most cases or ***vesicles.*** They are ***network-like*** in the WBC of man.

Mitochondria contain one or more DNA called ***mitochondrial DNA*** or ***mDNA***. It is circular in shape. It is double stranded. It can self replicate. It can also produce RNA like that of nuclear rDNA.



Mitochondrial DNA.

Origin of Mitochondria

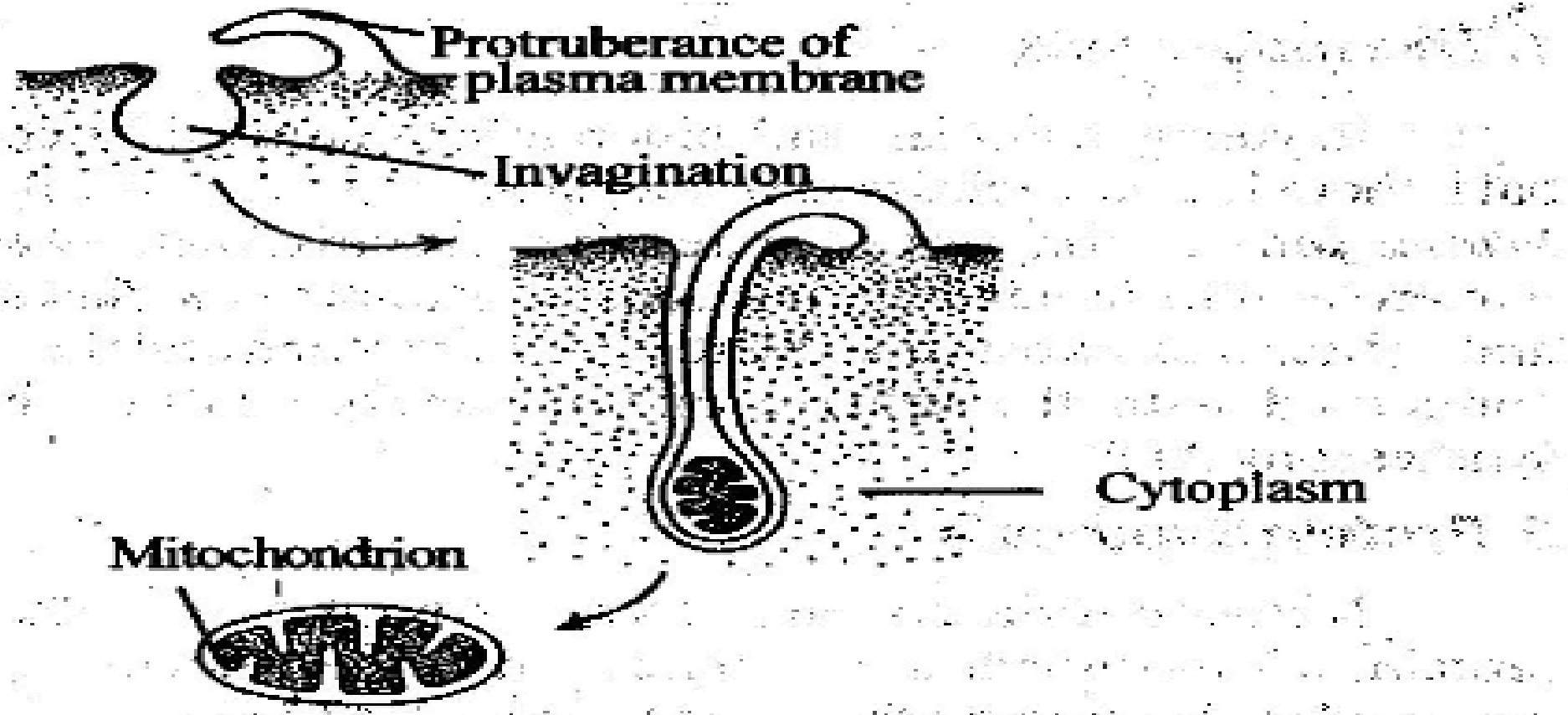
Origin of Mitochondria

The following hypotheses have been postulated for the origin of mitochondria :

1. Division of Pre-Existing Mitochondria: The new mitochondria originate by the division of the pre-existing mitochondria. Sometimes the mitochondria become elongated and broken into small pieces. Each piece forms a new mitochondrion in later stages.

2. Origin from the E.R. or Plasma membrane: The mitochondria may be formed from the growth and influx of membranes from the plasma membrane as well as from the endoplasmic reticulum.

3. De Novo Origin: The mitochondria may be synthesized from non-mitochondrial fragment. But there is no direct evidence for this hypothesis.



Origin of mitochondria from plasma membrane.

4. *Prokaryotic Origin:* According to ***Altmann*** and ***Schnimper*** (1890), the mitochondria might have originated from prokaryotic cells like bacteria. The bacteria entered the cells as parasites. In the course of time they maintained a ***symbiotic relationship*** with the eukaryotic cells. These form the mitochondria.

Functions of Mitochondria

Mitochondria perform the following functions:

1. *Thermogenesis*
2. *Protein synthesis*
3. *Synthesis of steroid hormones*
4. *Urea cycle*
5. *Calcium accumulation*
6. *Energy supply*

7. *Cellular respiration*
8. *Oxidative decarboxylation*
9. *Kreb's cycle*
10. *Electron transport system*
11. *Oxidative phosphorylation*

1. 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.

2. 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*.

3. Synthesis of Steroid Hormones

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

4. 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.

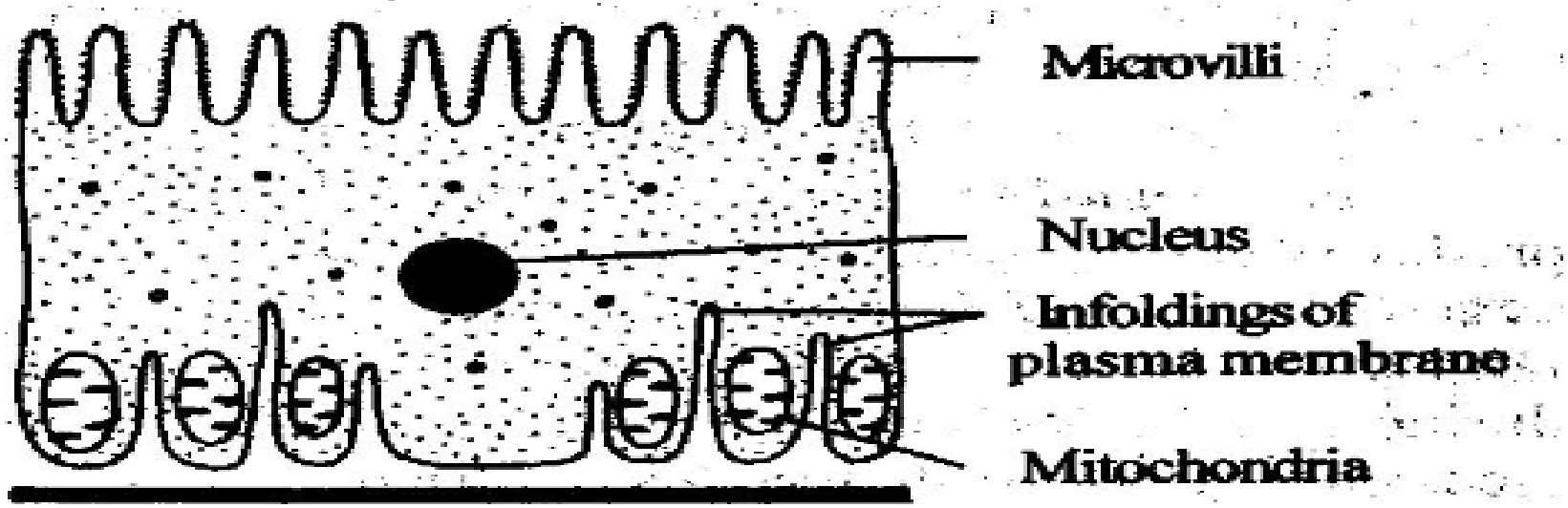
5. Calcium Accumulation

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.

6. *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.



7. 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

a. Glycolysis: Glycolysis occurs inside the cytoplasm but outside mitochondria. Mitochondrion has nothing to do with glycolysis. Glycolysis does not require oxygen and hence it is an ***anaerobic process.***

Glycolysis is a series of enzymatic reactions which convert ***glucose*** into ***pyruvic acid.*** The various steps involved in glycolysis are worked out by ***Embden*** and ***Meyerhof*** and hence it is also called ***Embden- Meyerhof pathways.***

During glycolysis two hydrogen pairs are released. The hydrogen pairs enter the mitochondria and are processed by the electron transport system for the synthesis of ATP.

b. Oxidative decarboxylation: The pyruvic acid produced during glycolysis enters the mitochondria. It is degraded to ***acetyl CoA*** by oxidation and decarboxylation. During ***oxidation*** a pair of hydrogens (2H) is removed and during decarboxylation a CO_2 is removed. The H enters the

$$\text{Pyruvic acid} + \text{CoA} \longrightarrow \text{Acetyl CoA} + CO_2 + H_2$$

During this process two hydrogen atoms are released. The two hydrogen atoms are accepted by NAD, and the NAD becomes reduced to $NADH_2$

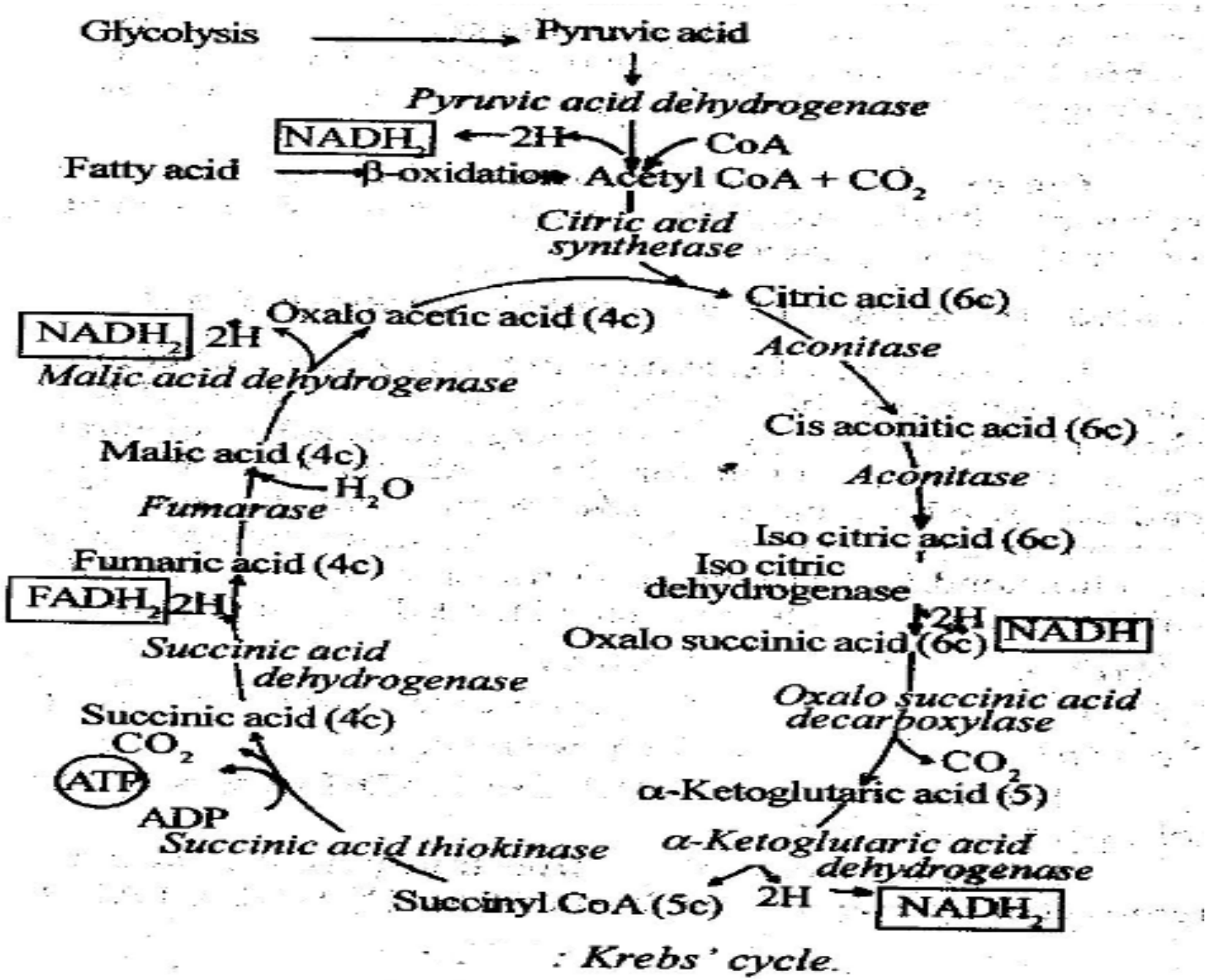
$$NAD + H_2 \longrightarrow NADH_2$$

The $NADH_2$ enters the electron transport system and it is oxidised.

c. Krebs' Cycle: The degradation of acetyl CoA into oxaloacetic acid through a series of steps is called ***Kreb's cycle.*** It is an aerobic process and it occurs inside the mitochondria. It releases four hydrogen pairs and one ATP molecule. The hydrogen pairs enter the electron transport system.

Krebs cycle takes place mainly in the mitochondria. It involves the following steps:

1. *Formation of citric acid*
2. *Dehydration*
3. *Hydration*
4. *Dehydrogenation I*
5. *Decarboxylation*
6. *Oxidative-decarboxylation*
7. *Oxidation*
8. *Hydration*
9. *Dehydrogenation II*


Glycolysis
Pyruvic acid
Pyruvic acid dehydrogenase
NADH2
2H
CoA
Fatty acid
β-oxidation
Acetyl CoA + CO2
Citric acid synthetase
Citric acid (6c)
Aconitase
Cis aconitic acid (6c)
Aconitase
Iso citric acid (6c)
Iso citric dehydrogenase
2H
NADH
Oxalo succinic acid (6c)
Oxalo succinic acid decarboxylase
CO2
α-Ketoglutaric acid (5)
α-Ketoglutaric acid dehydrogenase
2H
NADH2
Succinyl CoA (5c)
Succinic acid thiokinase
ATP
ADP
CO2
Succinic acid (4c)
Succinic acid dehydrogenase
FADH2
2H
Fumaric acid (4c)
Fumarase
H2O
Malic acid (4c)
Malic acid dehydrogenase
NADH2
2H
Oxalo acetic acid (4c)

: Krebs' cycle.

Oxidative Phosphorylation

In the respiratory chain when a cytochrome transfers the electrons to an other cytochrome, enormous amount of energy is released. This energy is trapped by ADP molecule to form one molecule of ATP.

$$ADP + Pi + energy \longrightarrow ATP$$

The process of ATP formation, occurring during the oxidative reactions of Krebs' cycle is known as ***oxidative phosphorylation***.

$$C_6H_{12}O_6 + 6O_2 + 6H_2O + 38\ ADP + 38\ pi \xrightarrow[Enzymes]{Respiratory} 6CO_2 + 12H_2O + 38ATP$$

The ATP molecules are the intracellular energy carriers, having a readily utilizable source of energy. With the release of energy they are converted back to ADP.

d. Electron Transport system: The hydrogen pairs released in glycolysis, oxidative decarboxylation and Krebs cycle are oxidised in electron transport system to produce H_2O with the release of ATP. The enzymes for electron transport system reside in the mitochondria.

Electron Transport System or Respiratory Chain

It is a system of enzymes and coenzymes, where the reduced coenzymes like FADH, NADH are oxidised (FAD, NAD) to release energy. The energy released in electron transport system is used for the synthesis of ATP. The synthesis of ATP is called ***oxidative phosphorylation.*** The electron transport system occurs in the inner membrane of the mitochondria. The electron transport system contains mainly six components arranged in the following sequence:

1. *NAD*
2. *FAD*
3. *NADH*
4. *FADH*
5. *Cytochrome A and*
6. *Cytochrome A3*

The oxidation of FADH and NADH occurs by the following steps.

I. The initiation of electron transport system is the removal of hydrogen from the substrate (NADH or FADH)

Electron transport system.