Energy Converion: Mitochondria and Chloroplasts

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Energy Conversion

- Prokaryotes use plasma membrane to produce adenosine triphosphate (ATP) used in the cell function
- Eukaryotes use specialized membranes to convert energy and produce ATP
- In eukaryotes these membrane-enclosed organelles are:
  - Mitochondria in fungi, animals, plants, algae, protozoa
  - Plastids (Chloroplasts) in plants and algae

Energy Conversion

- Common pathway utilizing energy for biological uses in both mitochondria and chloroplasts is <u>chemiosmotic coupling</u>.

- **Chemiosmotic coupling**: Uses sunlight or food to convert energy requiring to drive reactions in organelles

Energy Conversion: Mitochondria

Mitochondria

- Present in almost all **eukaryotic** cells (Neuron cells vs muscle cells)
- Each cell contains hundreds to thousands of mitochondria
- About 20% of the volume of a eukaryotic cell
- Not part of endomembrane system
- Mobile

Mitochondria

- Mitochondria are about 1µm in diameter and 1-10 µm in length.

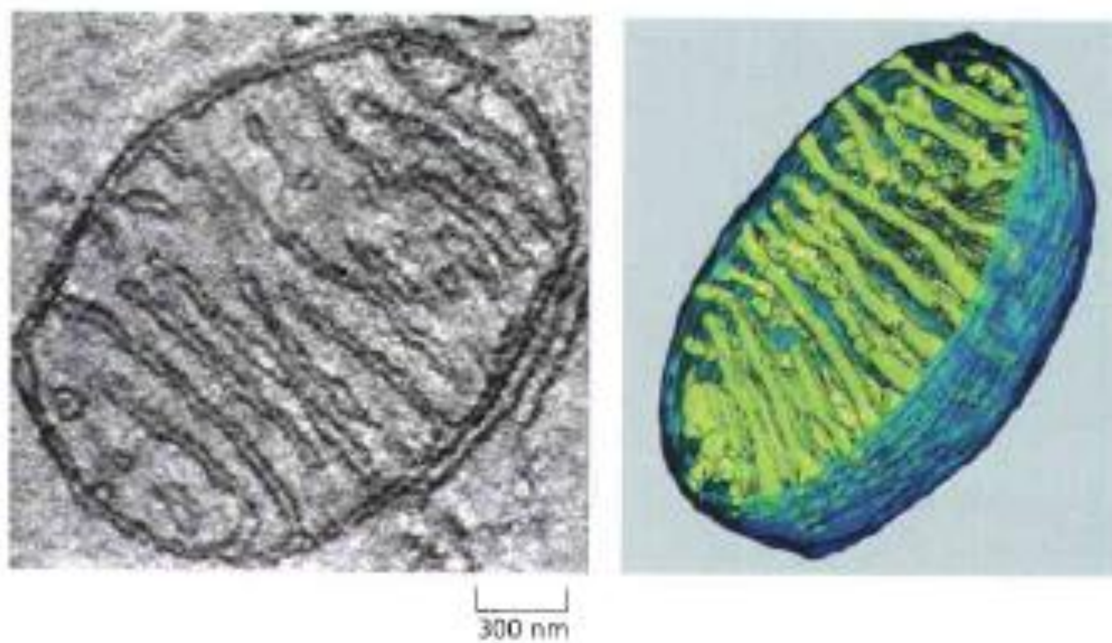


Figure 14 -8 The structure of a mitochondrion. Molecular Biology of the Cell, 5th Ed.

Mitochondria

- Capable of regenerating themselves without the whole cell undergoing division
  - grow and reproduce as semi-autonomous organelles

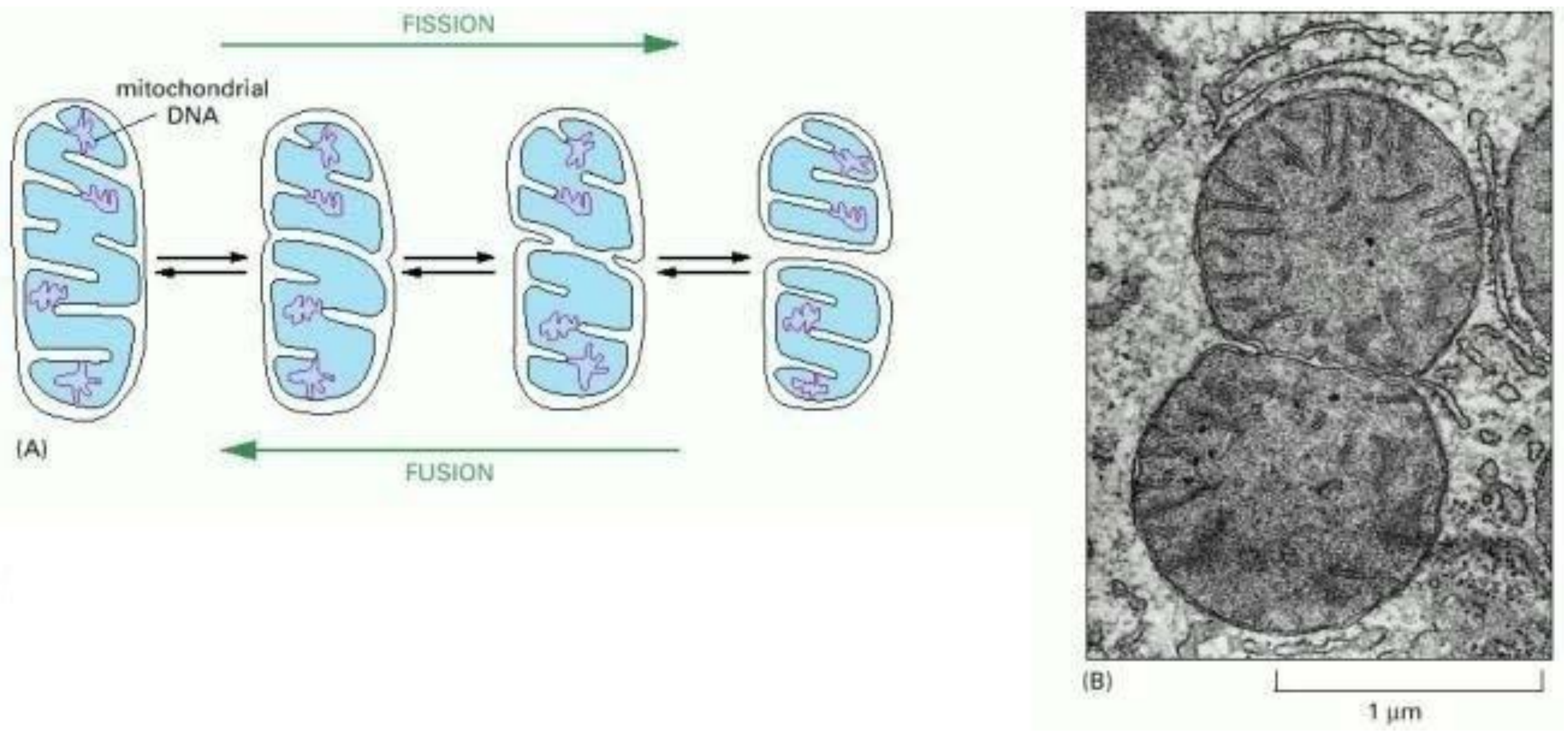
Mitochondria

- Number of mitochondria is different for each cell or for the same cell under different physiological conditions
  - eg. multiple spherical or cylindrically shaped organelles or single organelle with a branched structure

- Number of mitochondria is correlated with cell's metabolic activity
  - more activity = more mitochondria
  - Example: muscle and nerve cells

Mitochondrial Fusion

- Number and shape of mitochondria is controlled by the relative rates of mitochondrial division and fusion



Mitochondria

- Shape-changing
- Fusion and separation as they move
- As they move, they are associated with microtubules which determines the orientation and distribution of mitochondria in different cell types.

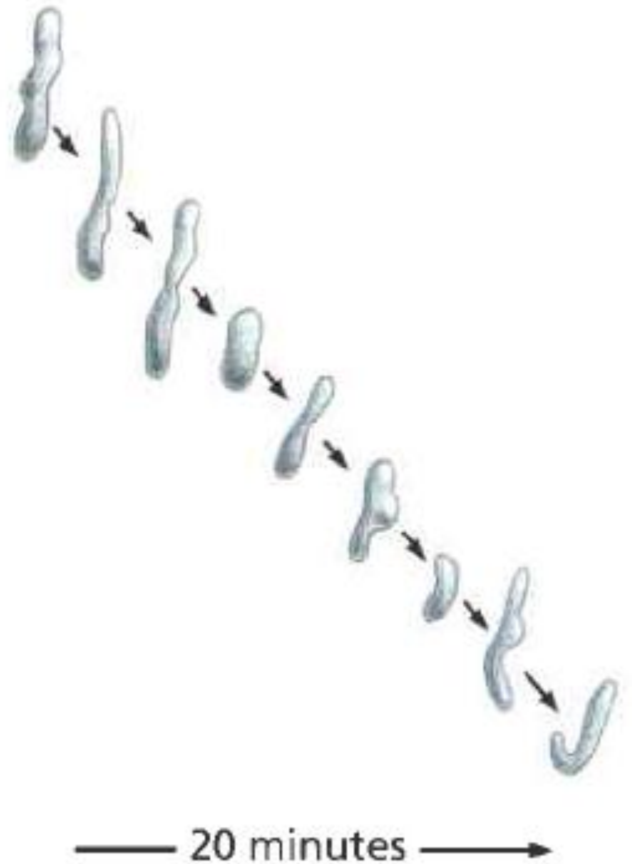


Figure 14.4 Mitochondrial plasticity. Molecular Biology of the Cell, 5th Ed.

Mitochondria

- In some cells
  - mitochondria forms a long moving filaments or chains OR
  - mitochondria remain fixed at the same position (eg in cells where they require excess amounts of ATP, such as cardiac muscle cell or flagellum in a sperm)

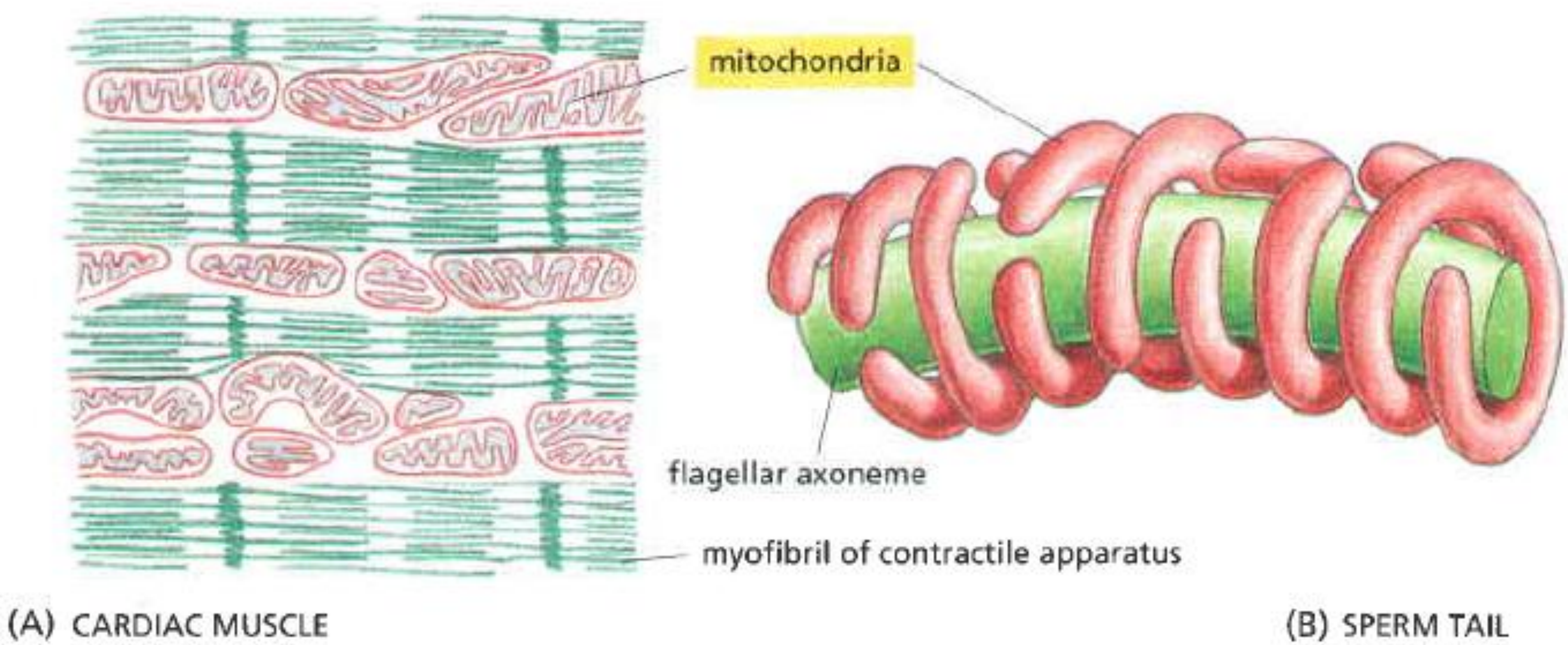


Figure 14.6 Localization of mitochondria near sites of high ATP utilization in cardiac muscle and sperm tail.

Structure of Mitochondria

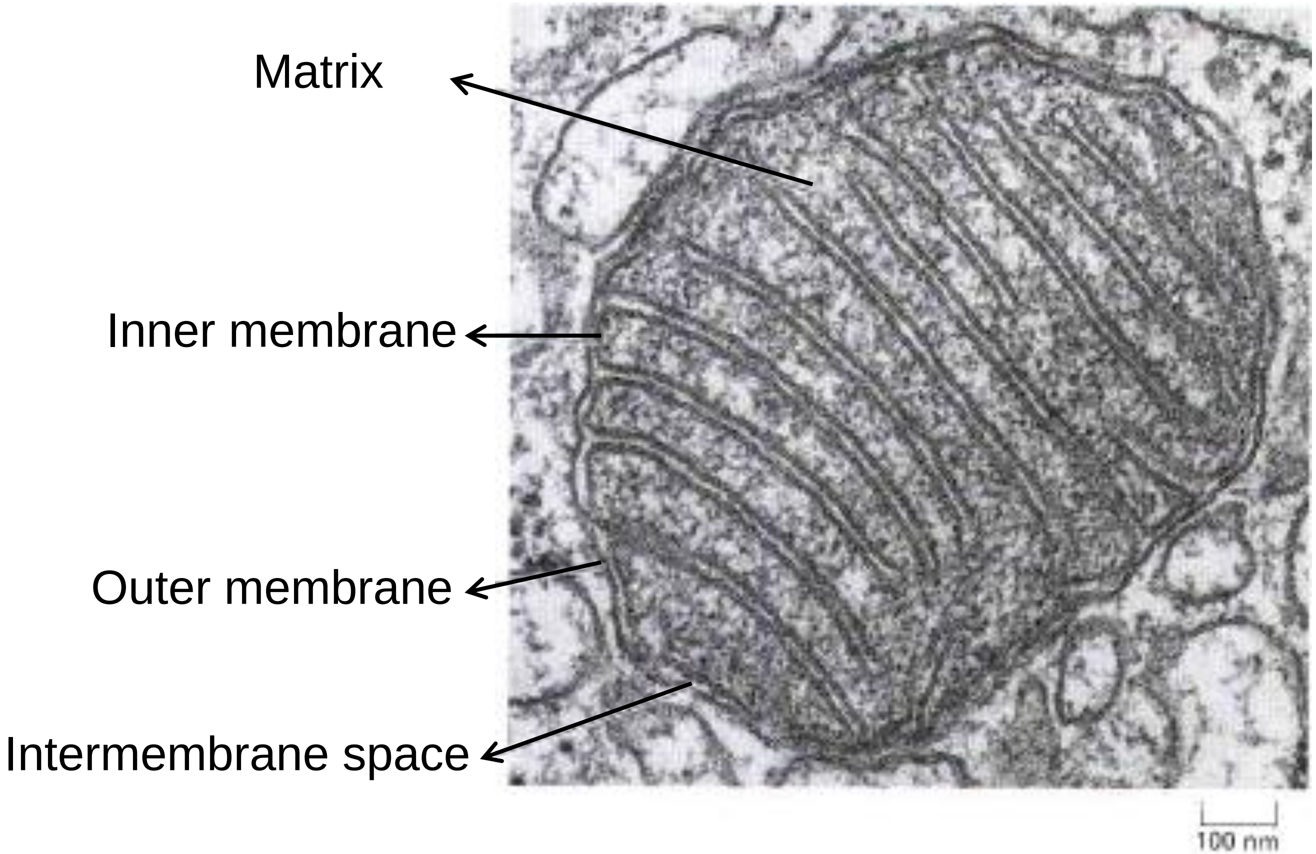
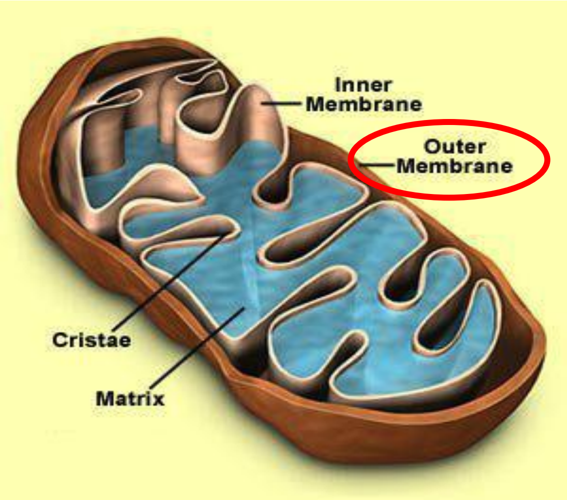


Figure 14 -8 The structure of a mitochondrion. Molecular Biology of the Cell, 5th Ed.

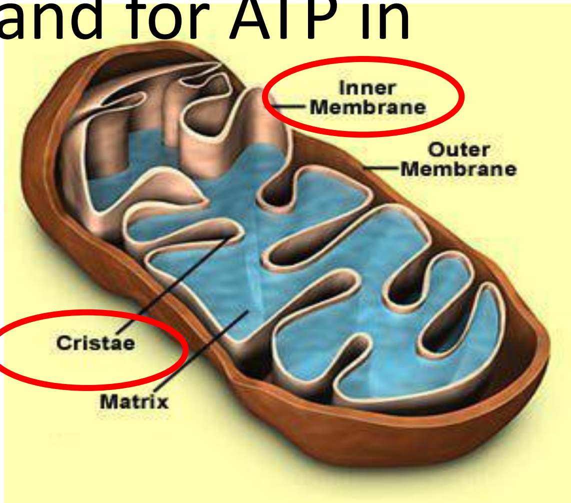
Structure of Mitochondria

- Double membrane: outer and inner membrane
- Outer membrane:
  - Smooth outer membrane
  - Separates inner membrane space from vacuole
  - It is permeable to molecules and enzymes involved in mitochondrial lipid synthesis



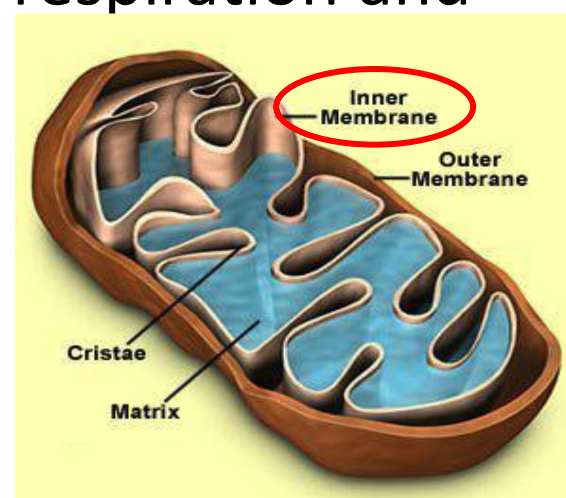
Structure of Mitochondria

- Inner membrane:
  - Major functioning part of mitochondria
  - Highly folded inner membrane forming cristae to increase the total surface area
  - The number of cristae changes in different cell types, such as there is three times greater in the mitochondrion of a cardiac muscle cell than in the mitochondrion of a liver cell since they have a greater demand for ATP in heart cells



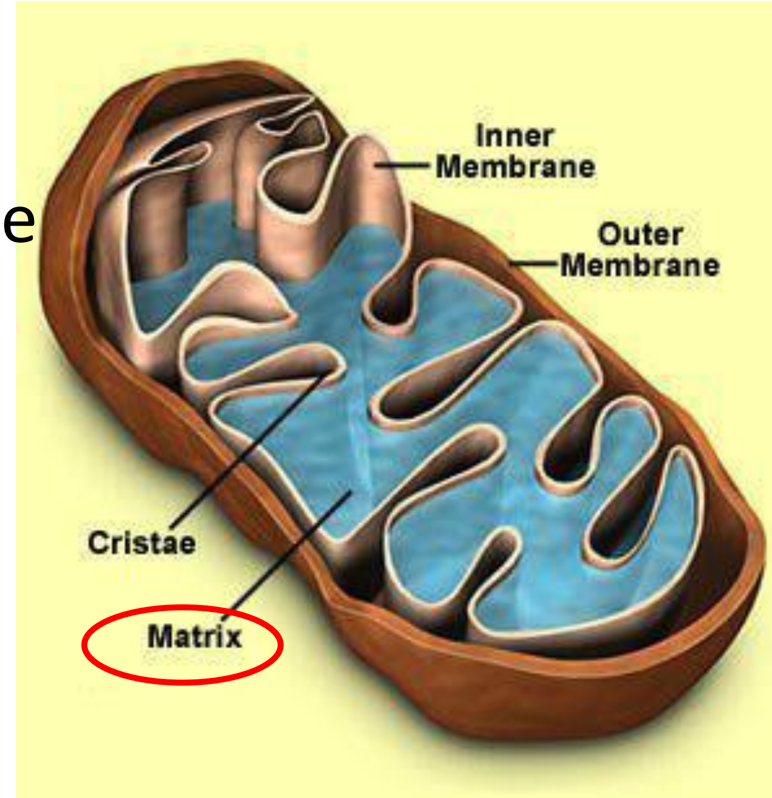
Structure of Mitochondria

- Inner membrane:
  - Impermeable to ions
  - Consists of
    - proteins functioning in oxidation reaction, in ATP synthase, transport proteins
    - Enzymes functioning in cellular respiration and ATP production



Structure of Mitochondria

- Matrix:
  - Major functioning part of mitochondria
  - Enclosed by the inner mitochondrial membrane
  - Consists of:
    - – Enzymes
    - – Mitochondrial DNA genome
    - – Mitochondrial ribosomes
    - – Mitochondrial tRNAs



Structure of Mitochondria

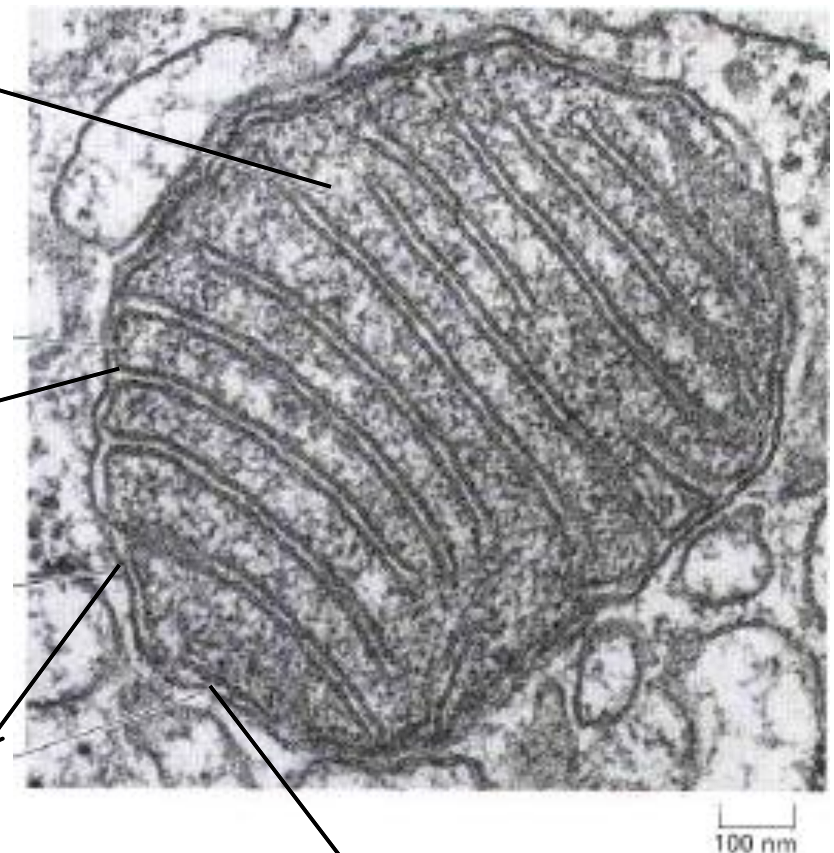
- Intermembrane space:
  - Chemically equivalent to cytosol
  - Narrow region between the inner and outer mitochondrial membrane
  - Consists of enzymes used in ATP passing out the matrix
  - Consists of porin molecules
    - Porin functions in protein transport and this is permeable to molecules of 5000 daltons or less (including small proteins)

Structure of Mitochondria

Matrix
- Krebs cycle
- Pyruvate oxidation
- DNA replication
- RNA transcription
- Protein translation

Inner membrane
- Site of ATP production
- Electron transport

Outer membrane
- Phospholipid synthesis
- Fatty acid desaturation and elongation
- ATP or sugar penetrate



Intermembrane space
- Functions in nucleotide phosphorylation

Figure 14 -8 The structure of a mitochondrion. Molecular Biology of the Cell, 5th Ed.

Why do cells need mitochondria?

- The powerhouse of the cell
- Provide energy for the cell
  - Motion
  - Division
  - Secretion
  - Contraction
- Sites of cellular respiration
  - Mitochondria generate most of the ATP that cells use to drive reactions
  - They use molecules and oxygen to produce ATP

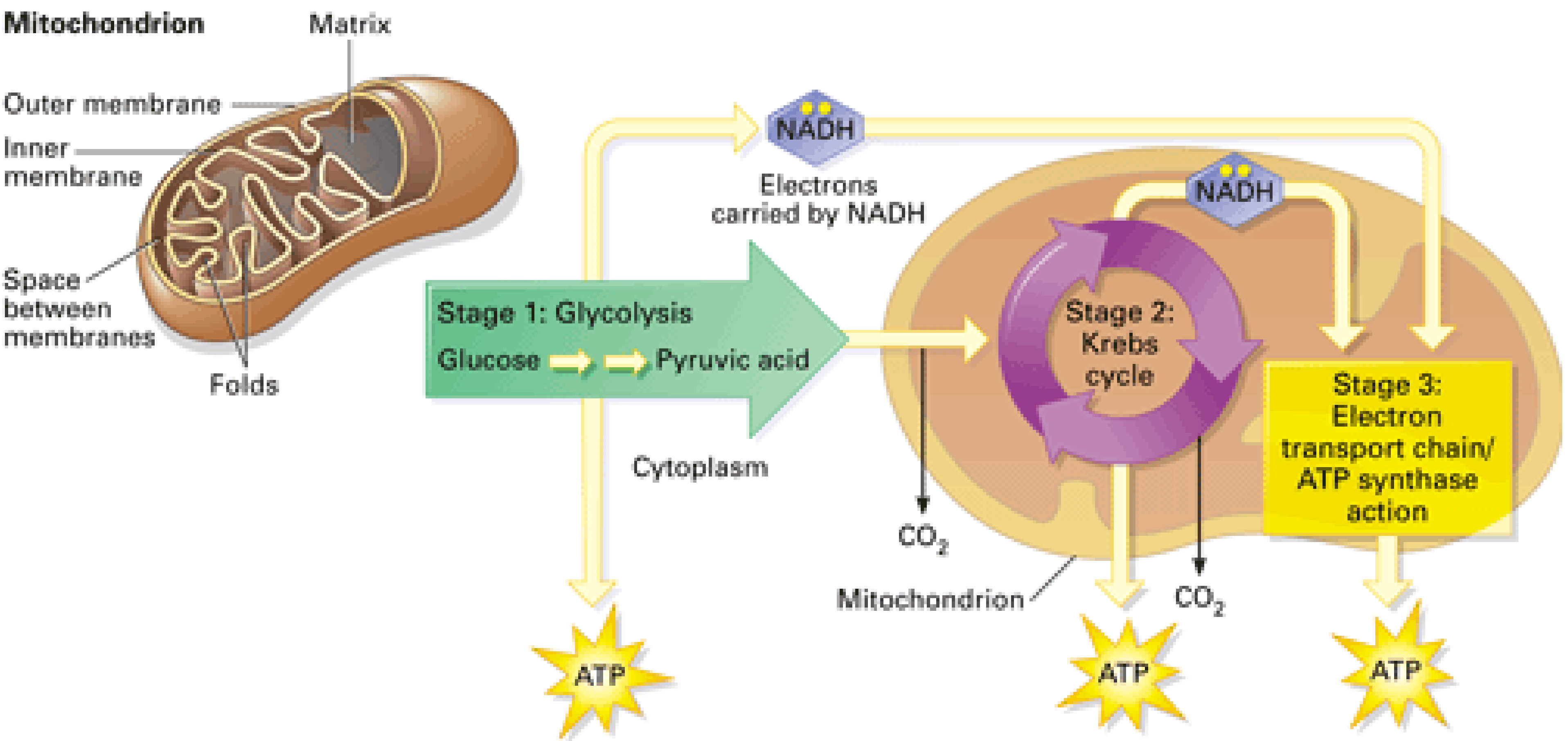
Why do cells need mitochondria?

Generating ATP:

- from breakdown of sugars and fats
  - Catabolism: break down larger molecules into smaller to generate energy
- In the presence of oxygen
  - Aerobic respiration: generate energy in presence of oxygen

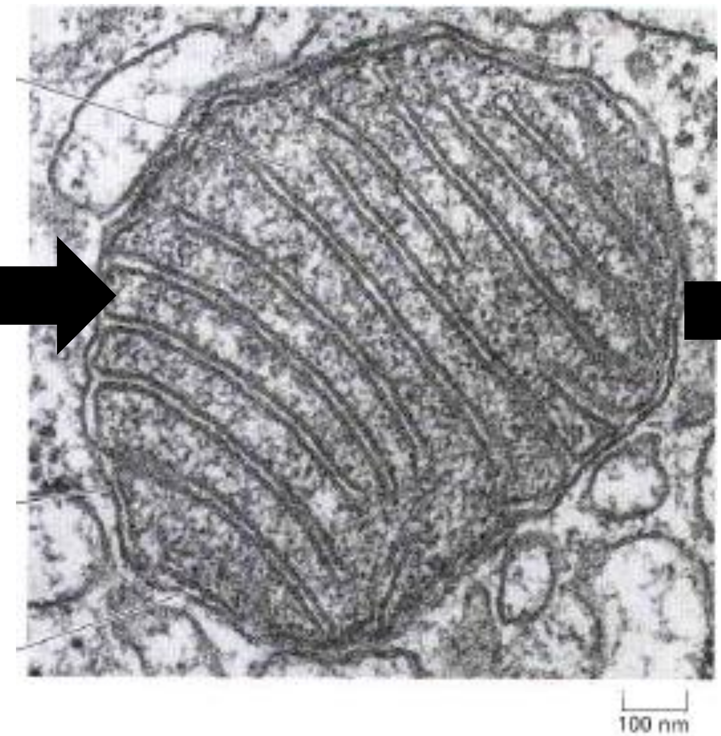
Why do cells need mitochondria?

- Site of Krebs cycle and oxidative phosphorylation (electron transport chain or respiratory chain)



To simplify:

Food molecules
(Pyruvate from sugars,
fatty acids from fats)
from cytosol and oxygen



ATP

Function of Mitochonria in the cell

- Mitochondria functions in metabolic activities:
  - Apoptosis-Programmed cell death
  - Cellular proliferation
  - Steroid synthesis
  - Lipid synthesis
  - Heat production (enabling organism to stay warm)

Abnormal functioning of mitochondria

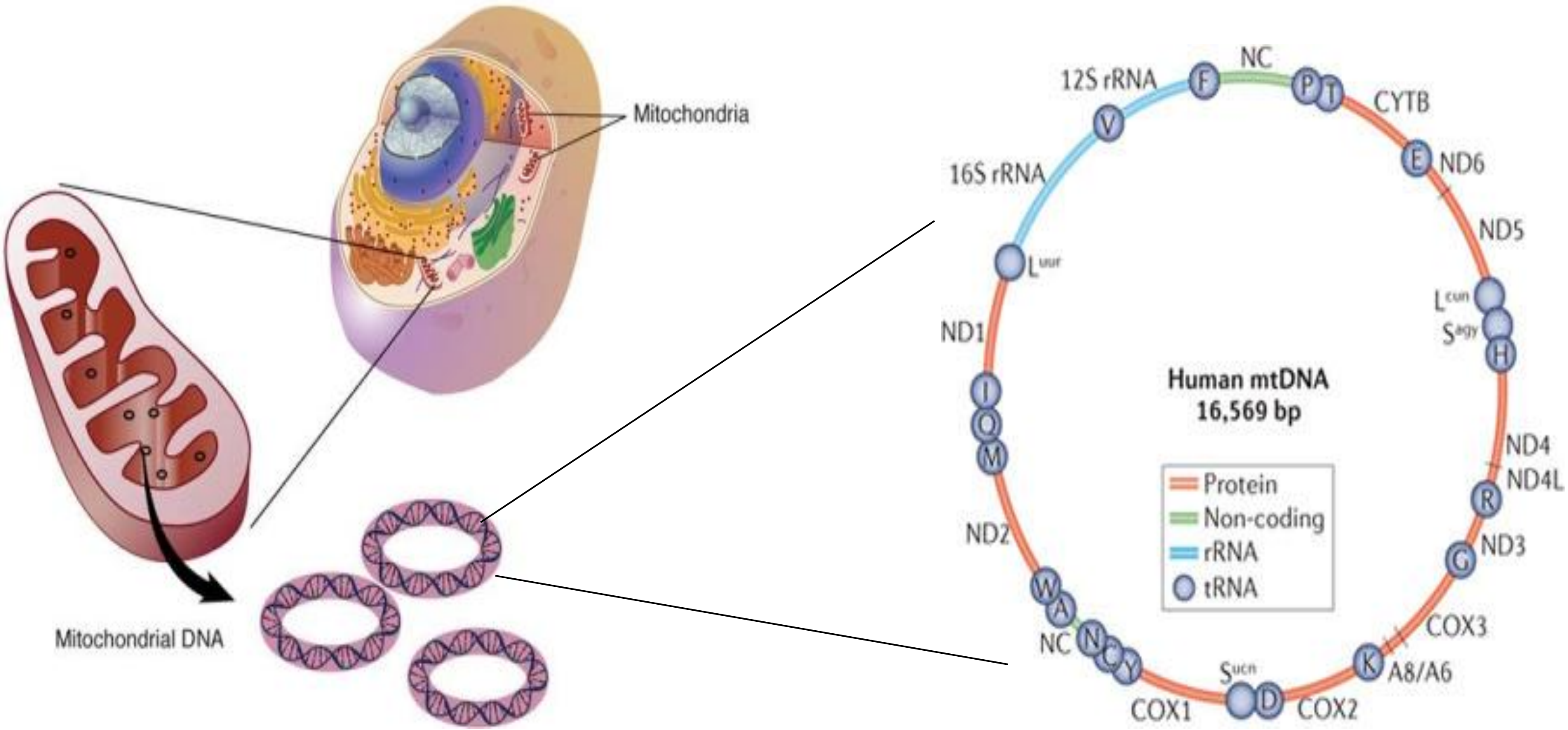
- Abnormal mitochondrial function leads to abnormalities in
  - Brain: developmental delays, mental retardation, migraines
  - Nerves: Weakness (which may be intermittent), absent reflexes, fainting
  - Muscles: weakness, cramping, muscle pain
  - Kidneys
  - Hearing loss or deafness
  - Cardiac conduction defects (heart blocks)
  - Liver
  - Hypoglycemia (low blood sugar), liver failure
  - Eyes

Mitochondria: Unique Organelle

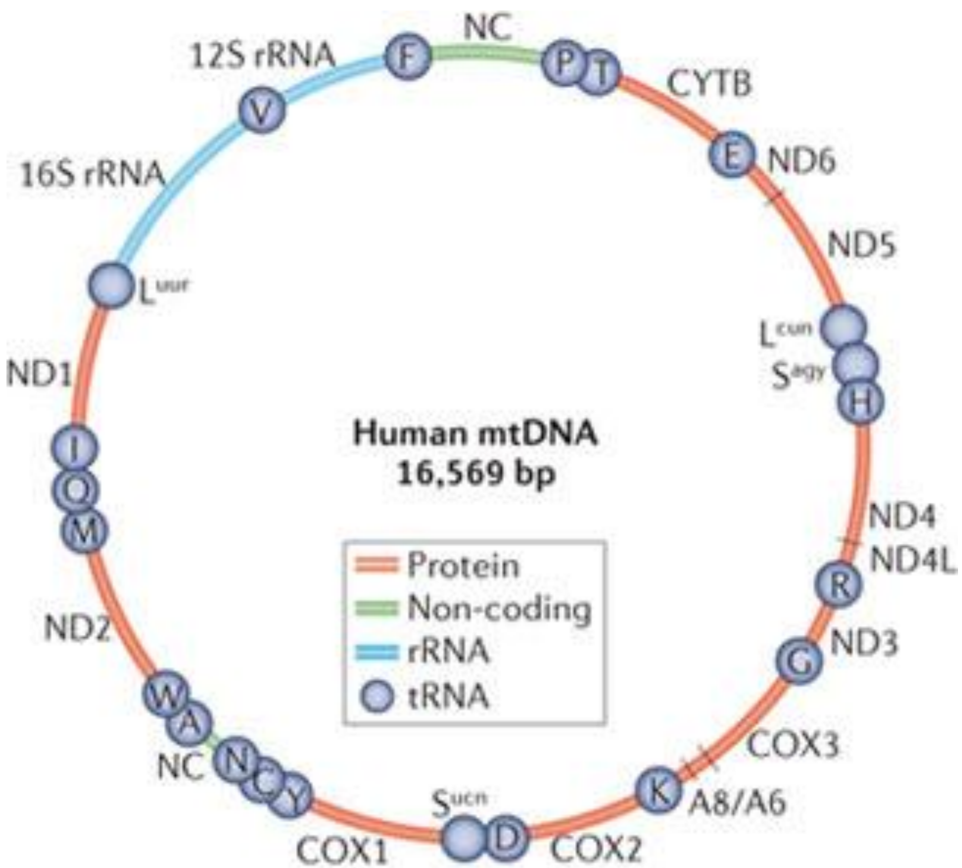
- All the mitochondria in your body came from your mother.
- Mitochondria have their own circular DNA
- Mitochondria have their own ribosomes

Mitochondial Genome

- The mitochondrial genome is a circle.



Mitochondrial DNA



- Each cell contains thousands of mitochondria and each has copies of its DNA
- More mitochondrial DNA in a cell than nuclear DNA (only 1 nuclear DNA in a cell)

Energy Conversion: Chloroplasts

Plastid

- Plastids are organelles found only in eukaryotic plant cells and algae.
- Plastids contain pigments such as chlorophyll and carotenoid.
- These pigments function to synthesize and store starch, protein and lipids.
- The type of pigments that the plastids determines the cell’s colour as colourful and colourless.

Proplastids

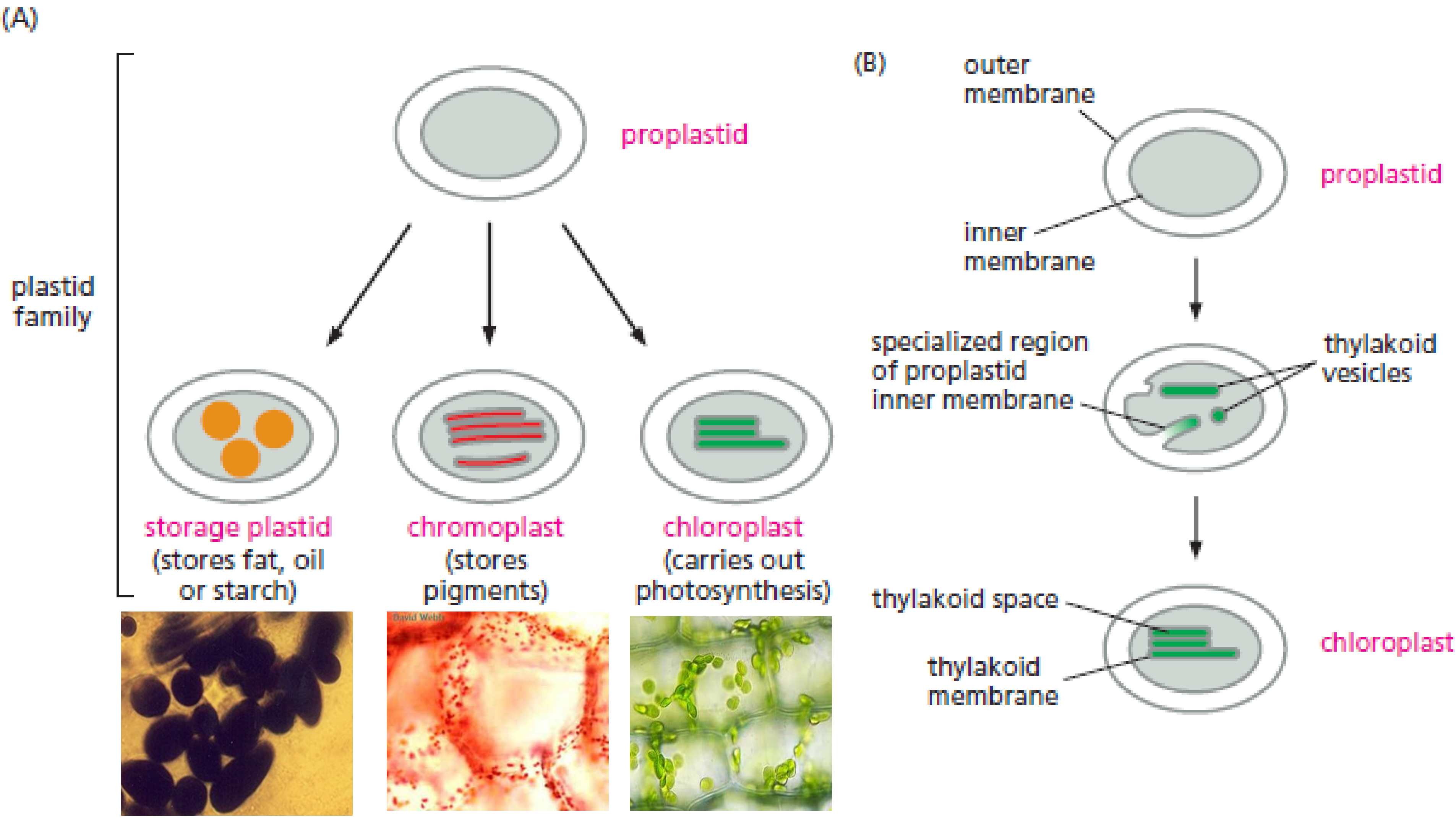
- A group of plant and algal membrane-bound organelles

- Proplastids are the undifferentiated form of plastids.

- Proplastids develop according to the requirements of each differentiated cell

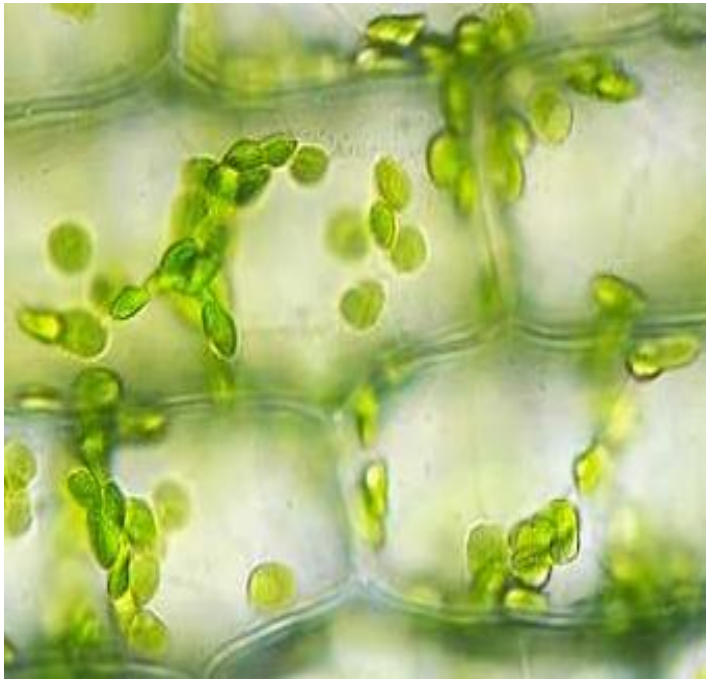
- They may develop into chloroplasts, chromoplasts and leucoplasts.

Proplastids



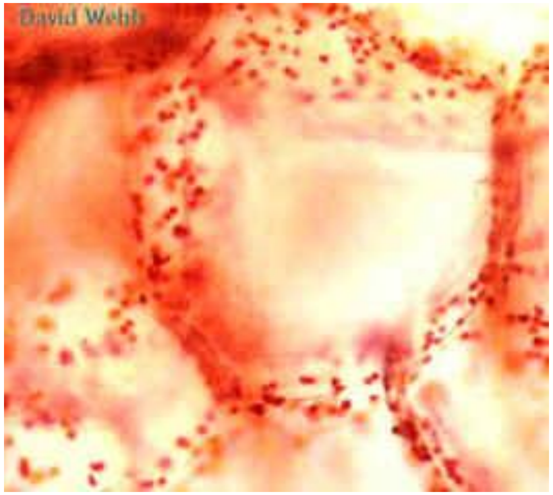
Proplastids: Chloroplasts

- Chloroplasts:
  - These are green plastids
  - They function in conducting photosynthesis.



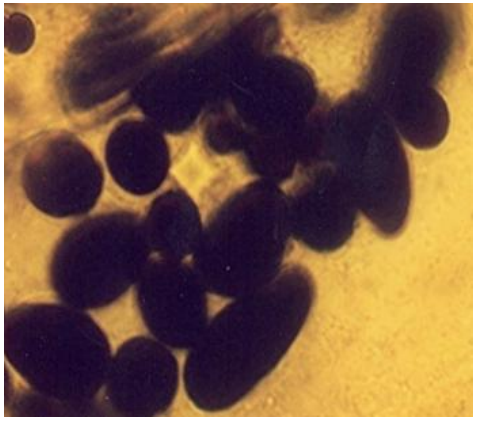
Proplastids: Chromoplasts

- <u>Chromoplasts</u>:
  - These are coloured plastids
  - They take part in pigment synthesis and storage.
  - They provide the orange and yellow color of fruits, flowers and autumn leaves.



Proplastids: Leucoplasts

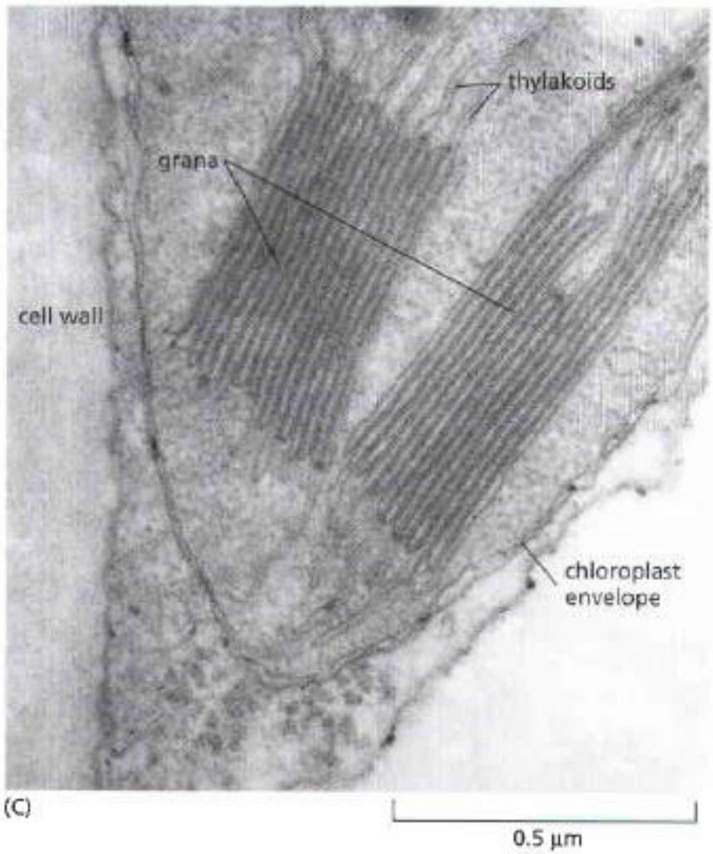
- Leucoplasts:
  - These are colourless plastids
  - They function in starch, protein and fat synthesis.
  - In some cases these plastids differentiate into:
    - Amyloplasts: function in starch storage
    - Proteinoplasts: function in storing and modifying protein
    - Elaioplasts (oleoplast): function in storing fat



Chloroplast

- Specialized version of plastids
- Found in plants and eukaryotic algae
- Not part of the endomembrane system
- Chloroplasts grow and reproduce as semi-autonomous organelles
- They have their own RNA, DNA and ribosomes
- Chloroplasts are mobile and move around the cell along tracks in the cytoskeleton

Structure of Chloroplasts



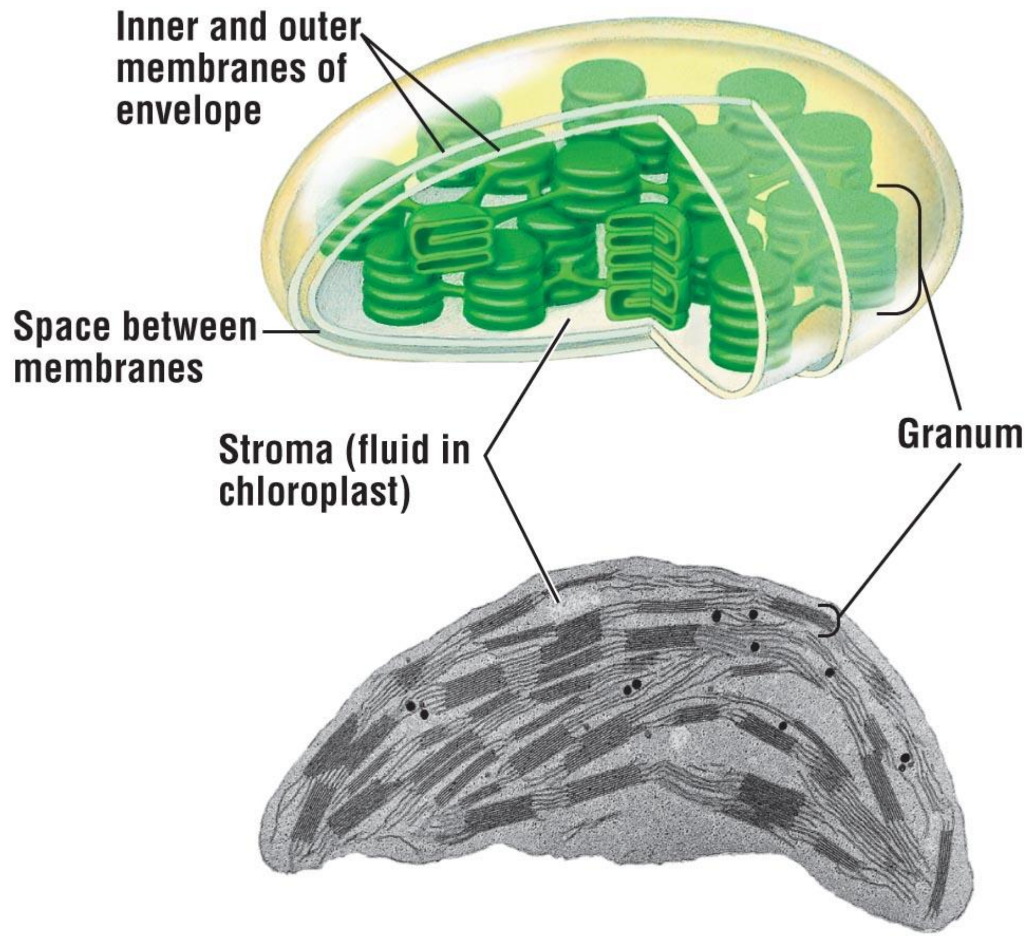


Figure 14-35 Electron micrographs of chloroplast.
Molecular Biology of the Cell. 5th Ed.

Structure of Chloroplasts

3 distinct membranes:

- Outer membrane
- Inner membrane
- Thylakoid membrane

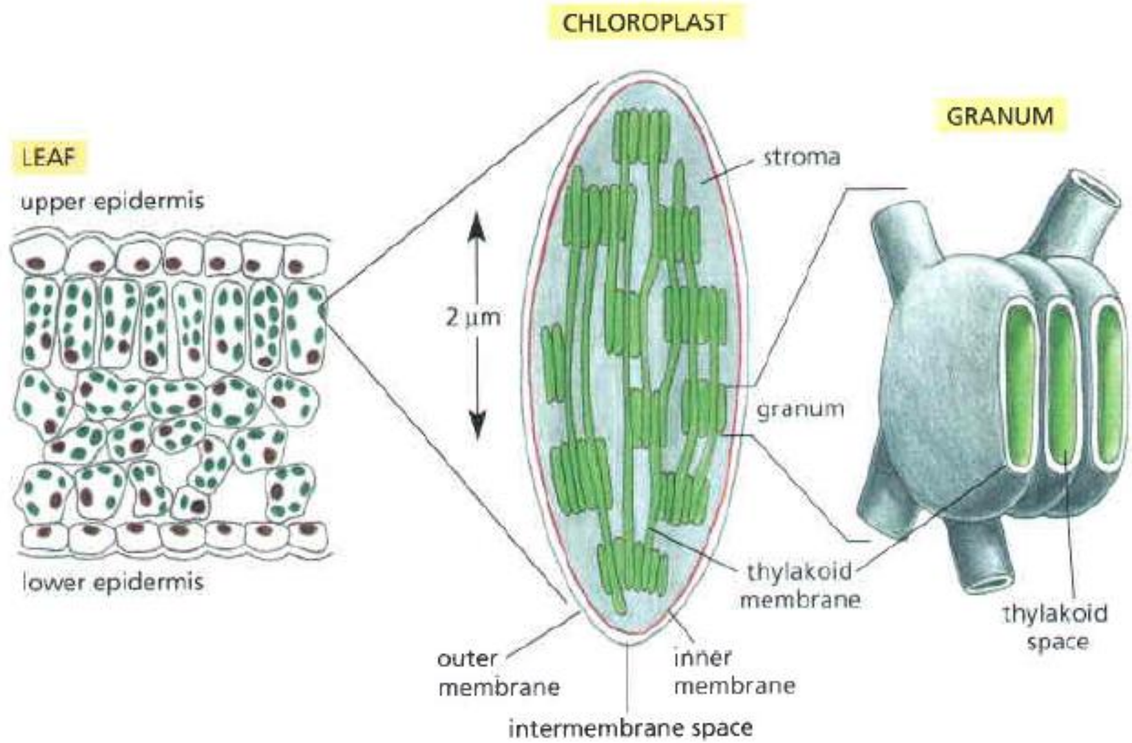


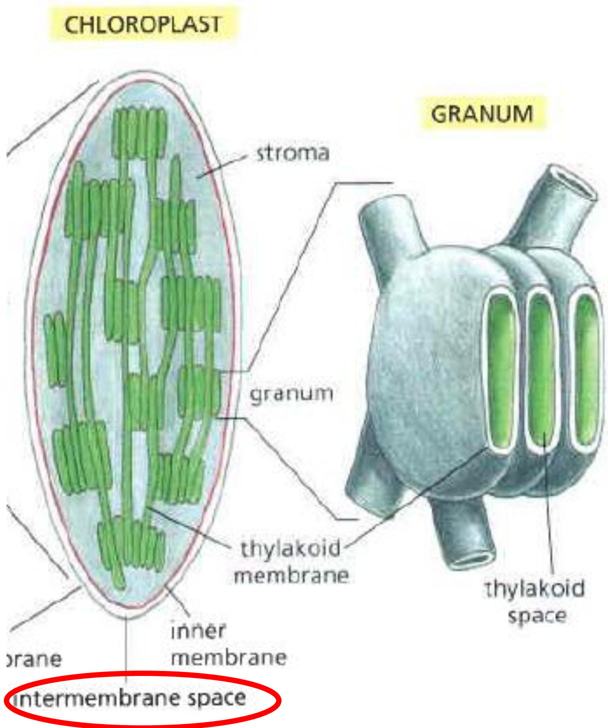
Figure 14-36 The chloroplast. Molecular Biology of the Cell. 5th Ed.

Structure of Chloroplasts

3 internal compartments:

1- Intermembrane Space:

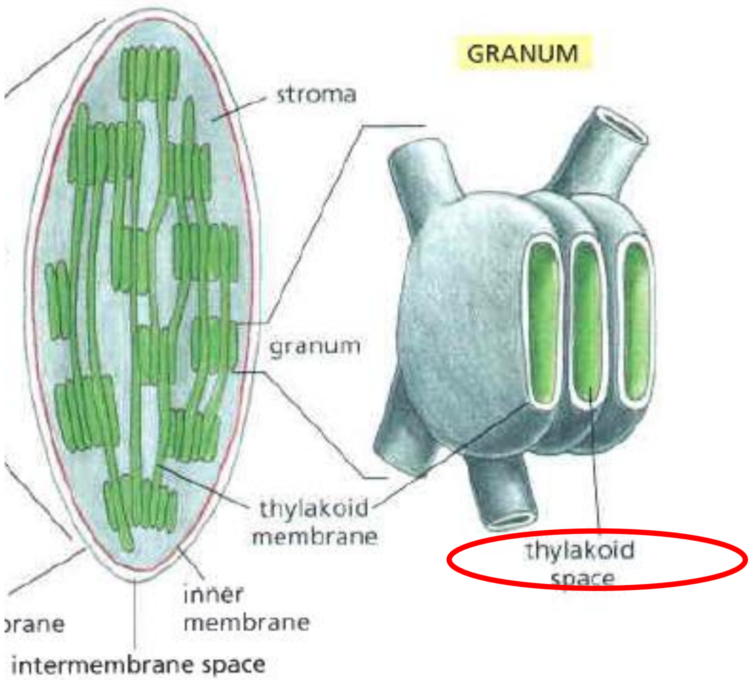
- bounded by a double membrane which partitions its contents from the cytosol
- narrow intermembrane space separates the two membranes.



Structure of Chloroplasts

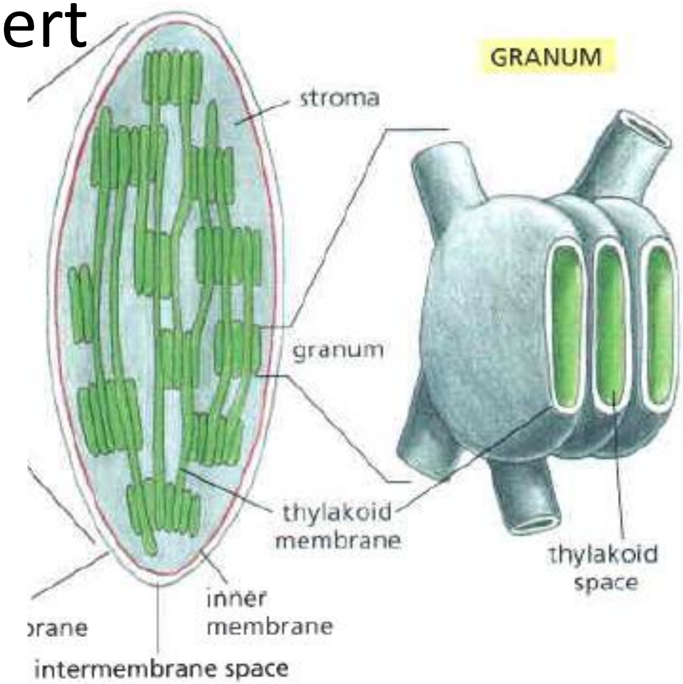
2- Thylakoid Space: Space inside the thylakoid

- Thylakoid membrane segregates the interior of the chloroplast into two compartments: thylakoid space and stroma
- Lumen of each thylakoid is connected with the lumen of thylakoid through thylakoid space



Structure of Chloroplast

- Thylakoids: Flattened membranous sacs inside the chloroplast
  - Chlorophyll is found in the thylakoid membranes (Responsible for green colouration)
  - Some thylakoids are stacked into grana
  - Photosynthetic reactions that convert
    - light energy to chemical energy
    - carbon dioxide to sugar

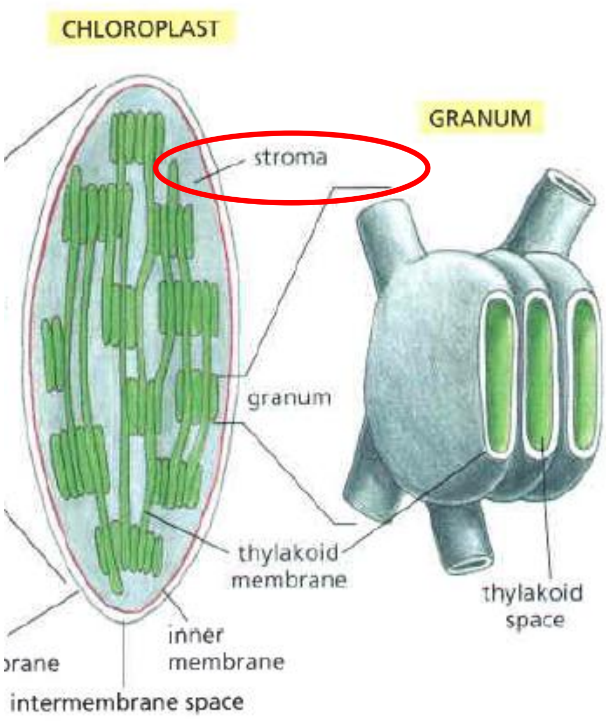


Structure of Chloroplast

3- Stroma: the fluid-filled space

- innermost membrane
- contains DNA, ribosomes and enzymes for photosynthesis

- Grana: Stacks of thylakoids in a chloroplast



Why do cells need chloroplasts?

- Site of photosynthesis
  - Chloroplasts convert sunlight into the first forms of cellular energy by:
  - Light reactions - energy transduction reactions
  - Dark reactions - carbon assimilation reactions

- Generate most of the ATP for the cells

- Storage of food or pigment molecules

Why do cells need chloroplasts?

- Metabolic reactions:
  - Purine and pyrimidine synthesis
  - Most amino acid synthesis
  - All of the fatty acid synthesis of plants takes place in the plastids

Photosynthesis

- Photosynthesis is the process that uses the energy in sunlight and carbon dioxide to create the organic materials required by cells

- Only occurs in plants, algae and some prokaryotes

- Photosynthesis occurs in chloroplast by chlorophyll

Photosynthesis

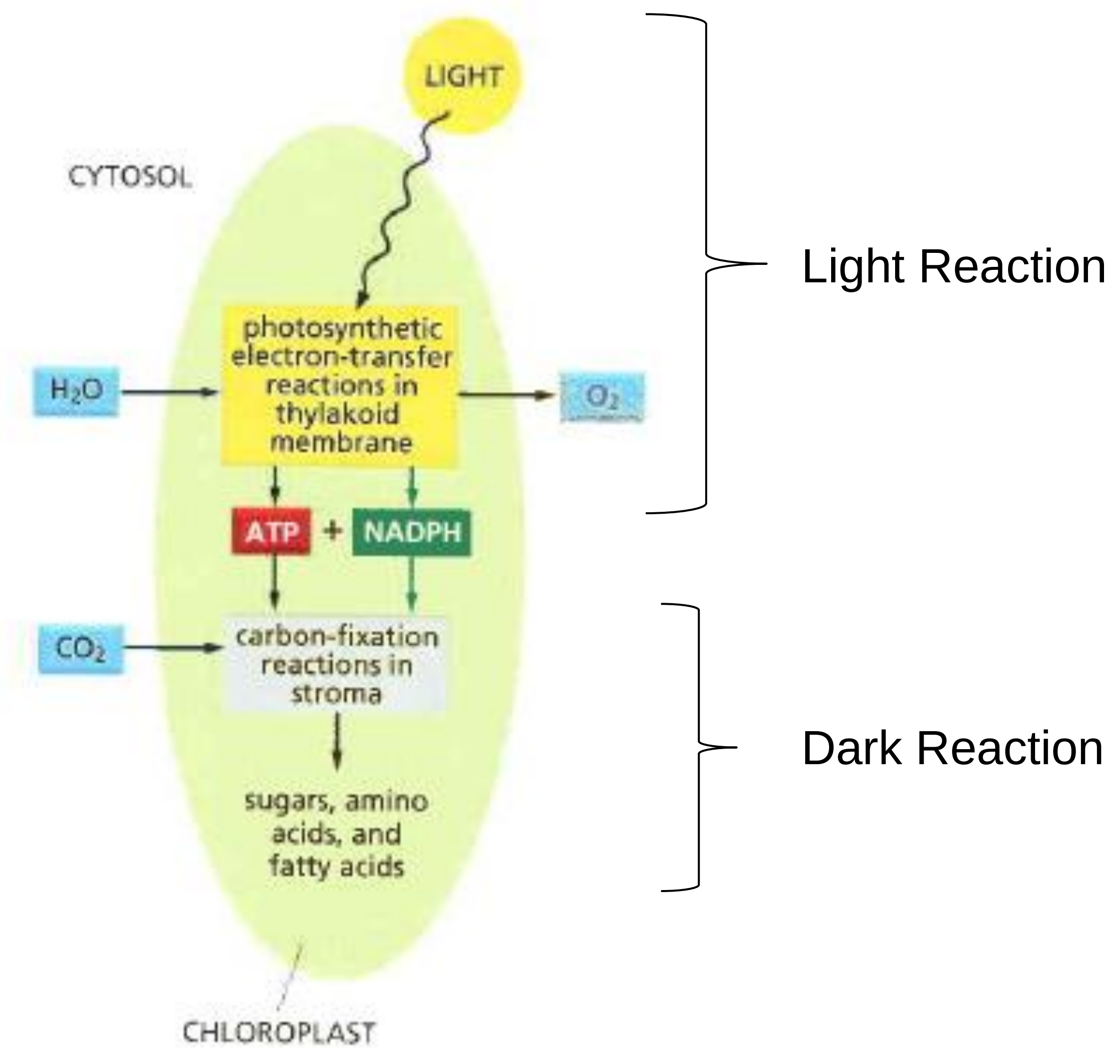


Figure 14-38 The reactions of photosynthesis. Molecular Biology of the Cell. 5th Ed.

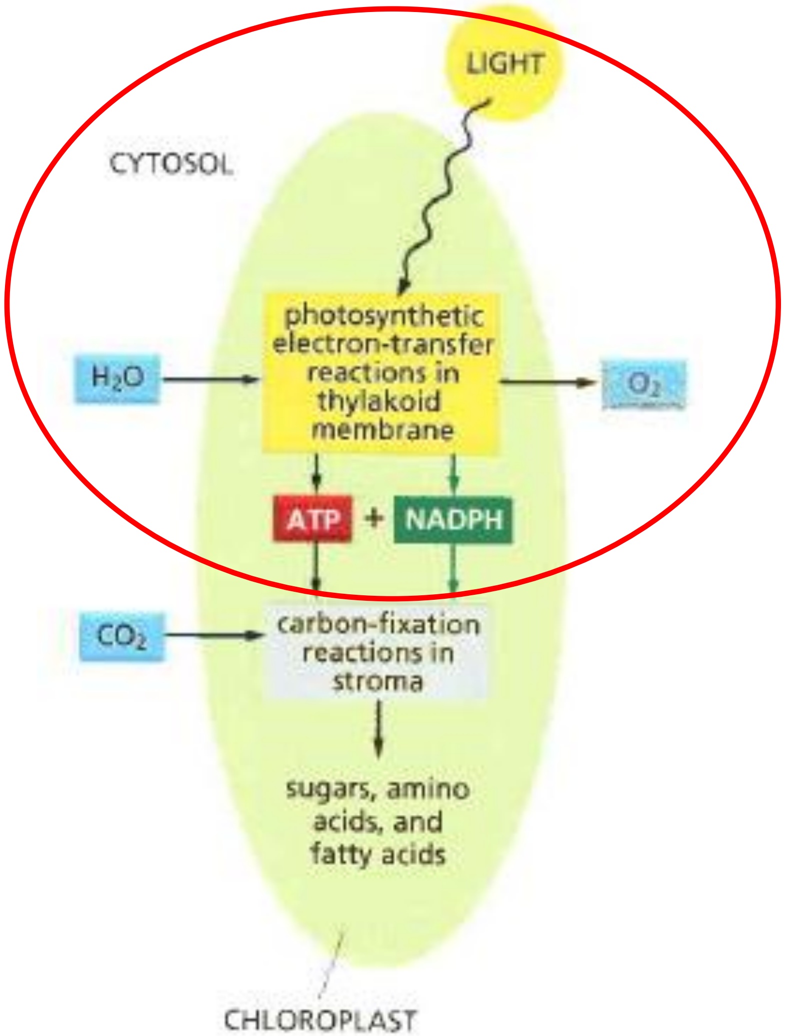
Photosynthesis: 2 stages

1- Light reactions (the *photo* part)

2- Dark reactions (Calvin cycle, the *synthesis* part)

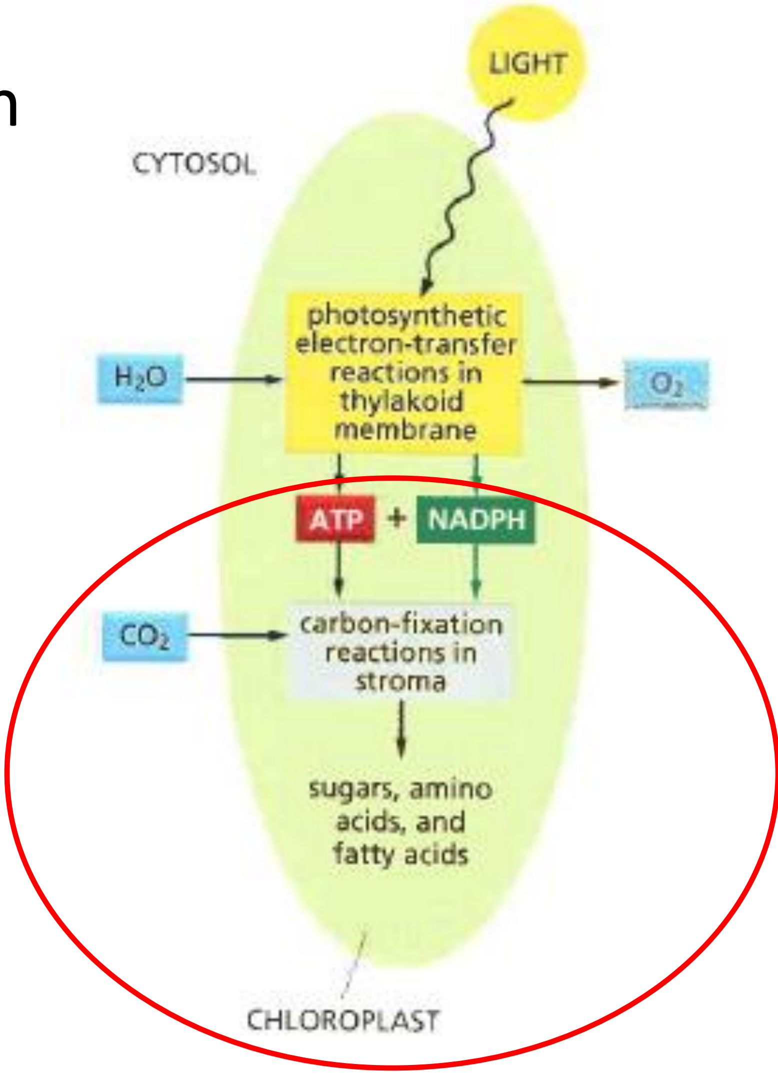
Light Reaction

- Light reaction:
  - in the thylakoids
  - Uses sunlight
  - Light or photosynthetic electron transfer reactions
  - Energy transduction reactions



Dark Reaction: Calvin Cycle

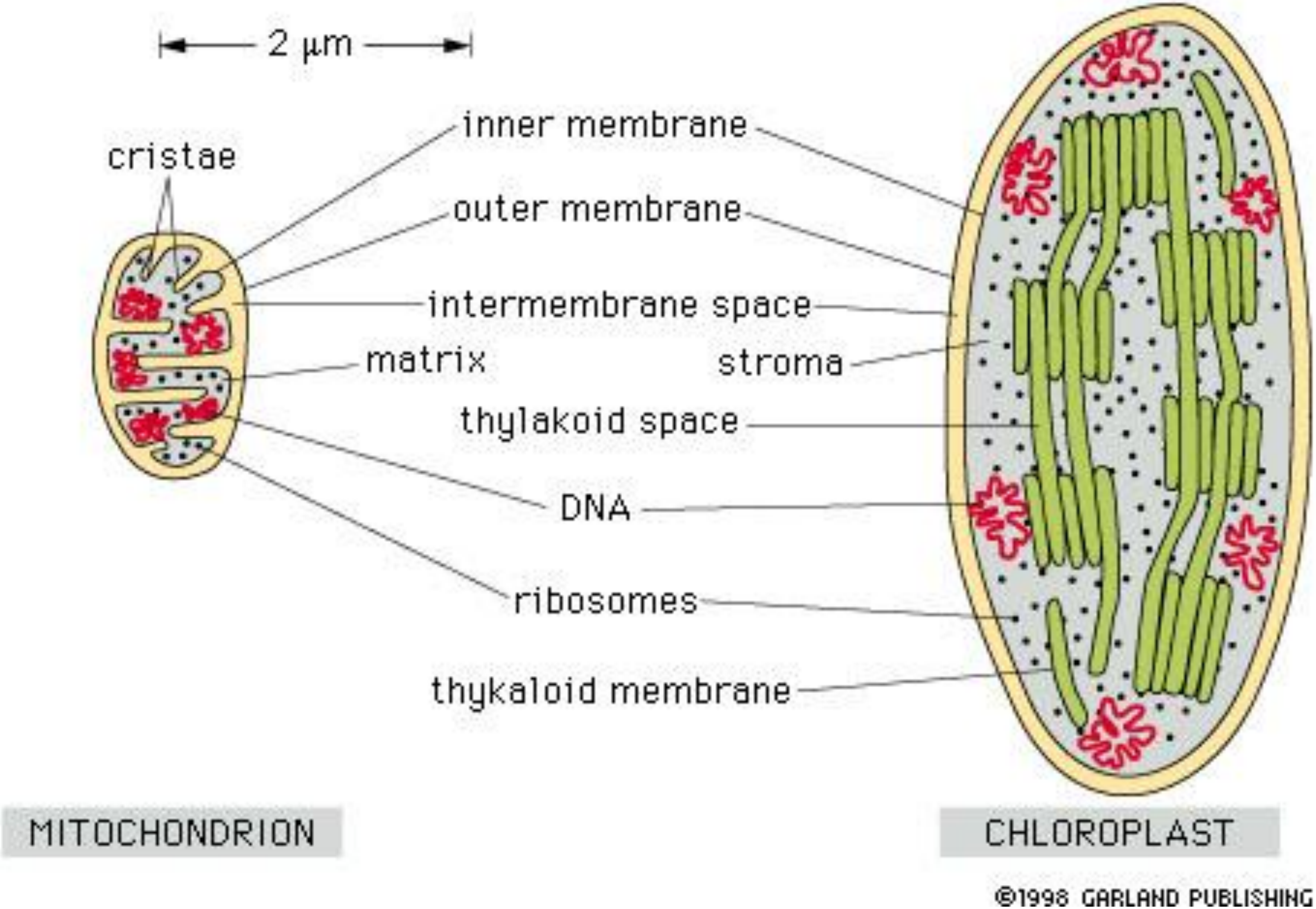
- Calvin cycle: dark or carbon-fixation reactions
  - in the stroma
  - Carbon fixation: incorporating CO_2 into organic molecules
  - forms sugar from CO_2, using ATP and NADPH
  - Converts carbon dioxide into glucose



What are the similarities and differences of the two organelles that are used in energy conversion?

Mitochondria vs Chloroplasts

Mitochondria vs Chloroplasts



Mitochondria vs Chloroplasts
Similarities and Differences

Mitochondria	Chloroplast
Plant and animal cells	Plant cells only
Create energy for the cell by converting food energy into ATP	Create energy for the cell by converting light into ATP
Takes place on cristae, identical to the inner membrane	Takes place on thylakoids, separate from membranes
Not part of endomembrane system	Not part of endomembrane system

Mitochondria vs Chloroplasts

Mitochondria	Chloroplast
Contain ribosomes and some DNA that programs a small portion of their own protein synthesis	Contain ribosomes and some DNA that programs a small portion of their own protein synthesis
Membrane proteins are not made in the ER, but by free ribosomes in the cytosol and by ribosomes located within themselves	Membrane proteins are not made in the ER, but by free ribosomes in the cytosol and by ribosomes located within themselves
Semi-autonomous (grow and reproduce within the cell)	Semi-autonomous (grow and reproduce within the cell)

Mitochondria vs Chloroplasts
Structural Similarities and Differences

Mitochondria	Chloroplast
Double membrane	Double membrane
Matrix	Stroma
Inner membrane folded forming cristae	Inner membrane is not folded
-	Additional internal membrane and space: thylakoid membrane and thylakoid space

Proteins in Mitochondria and Chloroplasts

- They import proteins from cytosol after they are synthesized on cytosolic ribosomes.

- The protein traffic between the cytosol and these organelles is unidirectional since proteins are normally not exported from mitochondria or chloroplasts to the cytosol.

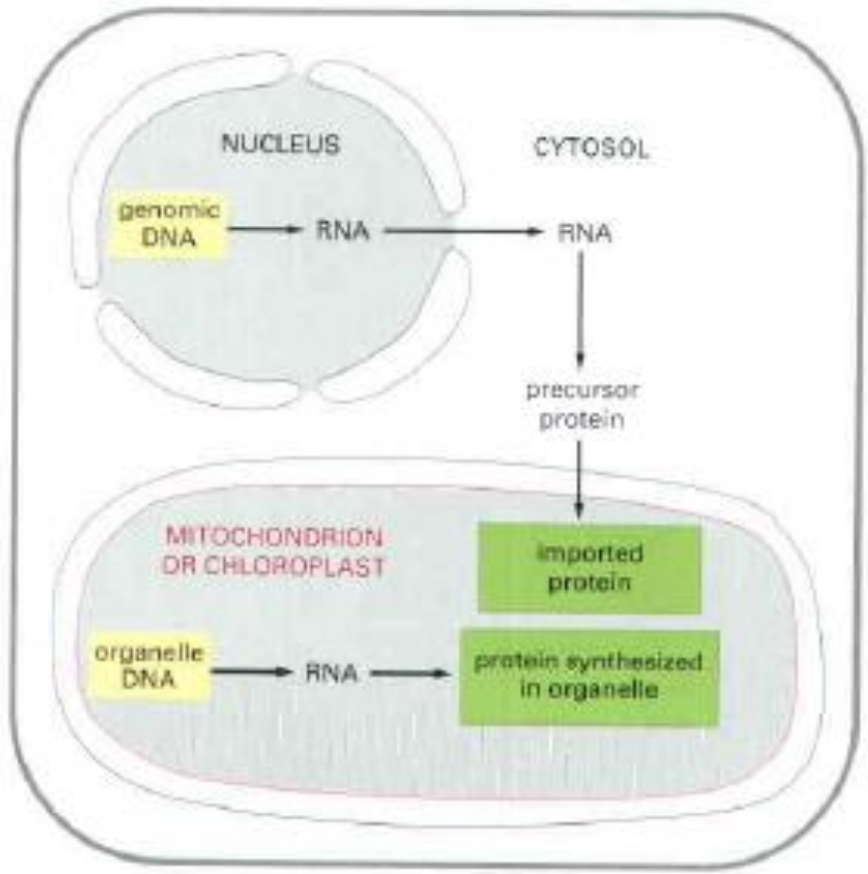


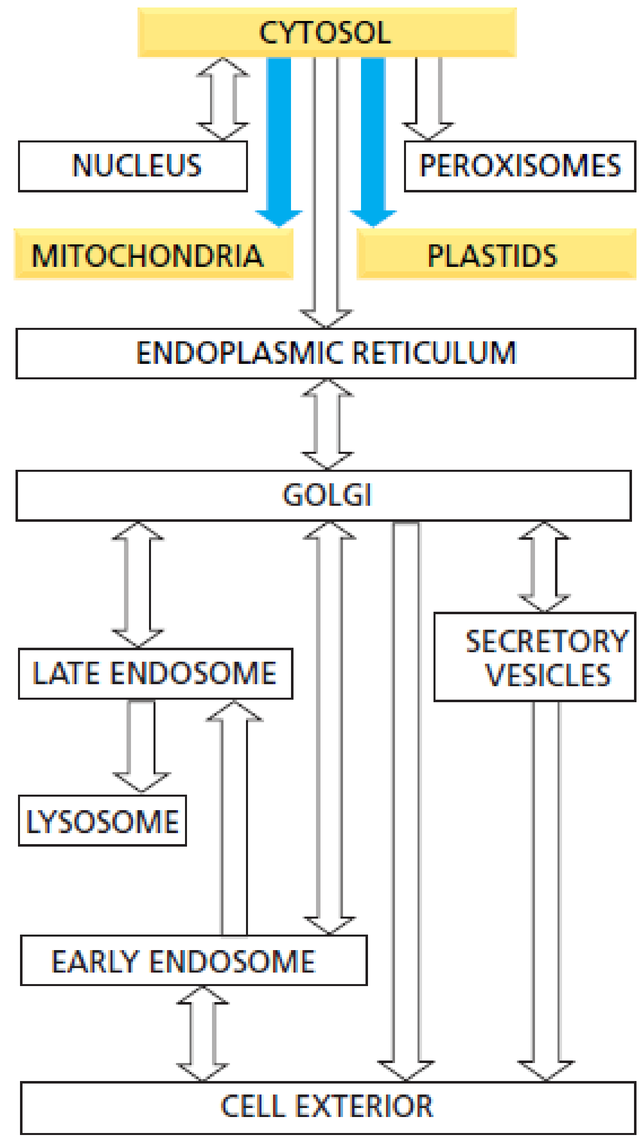
Figure 14-53 The production of mitochondria and chloroplast proteins by two separate genetic systems. Molecular Biology of the Cell. 5th Ed.

Protein Sorting

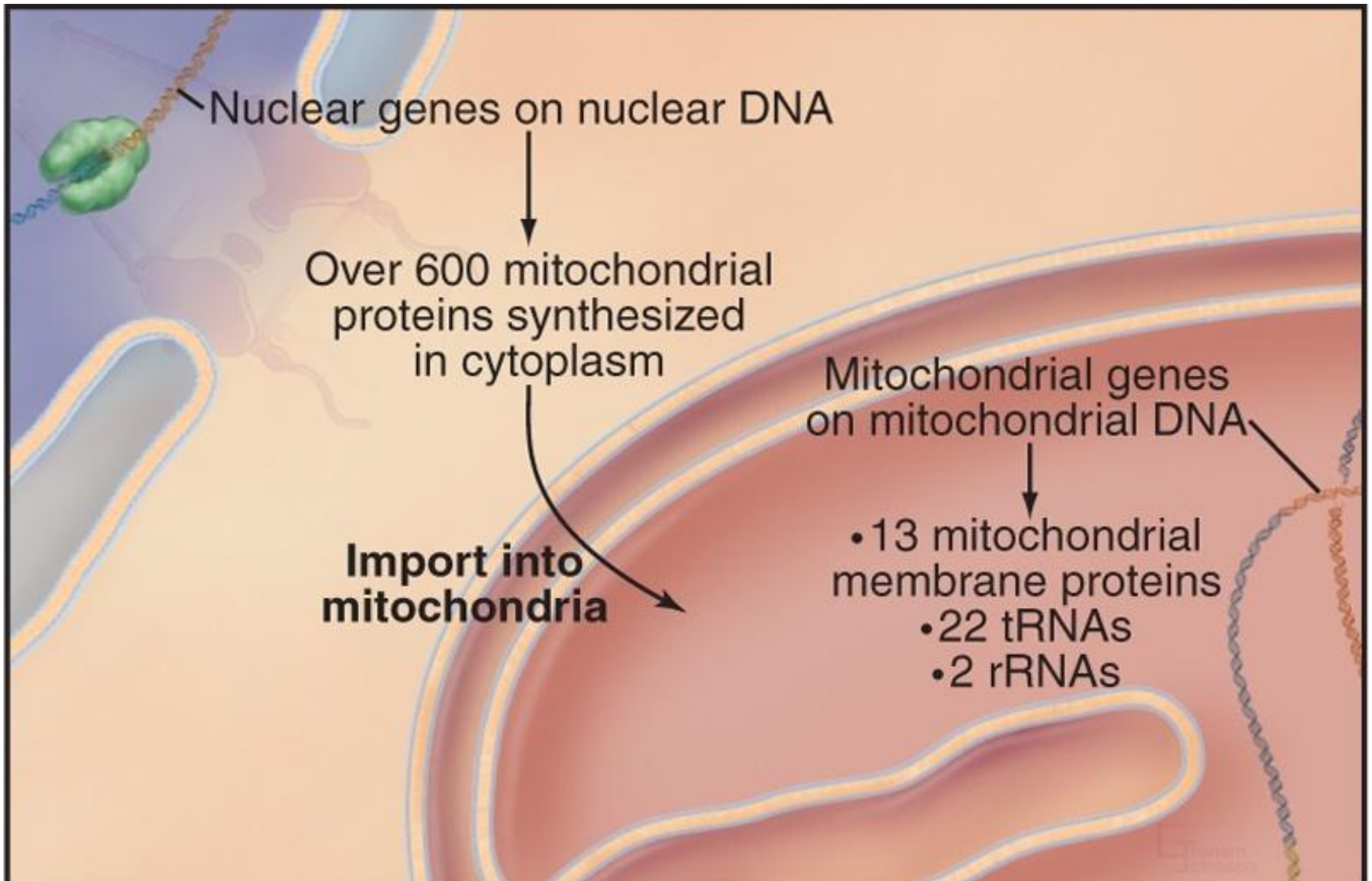
Remember from Previous Lecture!

Protein Sorting: Mitochondria and Chloroplast

- Most mitochondrial and chloroplast proteins are encoded by nuclear genes and imported from the cytosol.
- Proteins unfold to enter mitochondria and chloroplasts
- The protein is translocated simultaneously across both the inner and outer membranes at specific sites where the two membranes are in contact with each other



Protein Sorting: Mitochondria



Summary: Mitochondria

- Present in almost all eukaryotic cells
- Number of mitochondria is correlated with aerobic metabolic activity
- Capable of regenerating themselves without the whole cell undergoing division
- It is enclosed by two major membranes
- The inner-most space (matrix) and inner membrane are the major functioning parts

Summary: Mitochondria

- The powerhouse of the cell
- Produce most of cells ATP
- Functions in metabolic activities: Apoptosis-Programmed cell death, cellular proliferation, heme and lipid synthesis

Summary: Chloroplasts

- Specialized version of plastids
- Found in plants and eukaryotic algae
- Chloroplasts grow and reproduce as semi-autonomous organelles
- Site of photosynthesis
  - Chloroplasts convert sunlight into the first forms of cellular energy

Summary: Photosynthesis

- The energy entering chloroplasts as sunlight is converted into chemical energy (ATP)
- Sugar made in the chloroplasts supplies chemical energy and carbon skeletons to synthesize the organic molecules of cells
- In addition to food production, photosynthesis produces the oxygen in our atmosphere

Extra Reading:

Chapter 14: 813, 815-818, 840-844, 856-859